IMPACT OF MINING ON PLANT DIVERSITY AND COMMUNITY STRUCTURE OF AQUATIC AND TERRESTRIAL ECOSYSTEMS OF JAINTIA HILLS, MEGHALAYA

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I **Mr. S. Jeeva**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other university/institute.

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Chapter 1

General Introduction

Tropical forests are one of the major vegetation and the most diverse groups of terrestrial ecosystem of the globe. These forests are found in tropical and subtropical belts, and inhabit major populations of plant species, and act as reservoir of biodiversity (Valencia et al. 1994; Richards 1996; Whitmore 1998; Aiba and Kitayama 1999). The forests of Meghalaya are the best example of tropical and subtropical forests. Presently, these forests are facing threats because of anthropogenic disturbances. The degradation of ecosystems and destruction of habitats due to anthropogenic activities are the major causes of decline in global biodiversity. In view of the growing threat to biodiversity, it is important to see how natural communities and their structural attributes are affected by progressive erosion of biodiversity caused by anthropogenic disturbances (Mishra et al. 2004).

The investigation of anthropogenic impacts is central to studies of global environmental change and sustainable development (Fu et al. 1998; Gong et al. 2000; Wang and Gong 1998; Withers and Dil 1999; Shi et al. 2000). Apart from causing changes in the soil environment, land use and land cover changes are regarded as important components and primary cause of global environmental changes (Turner et al. 1995; Li 1996; Wang et al. 2004). Changes in land use leads to changes in land cover, which in turn directly affect terrestrial ecosystems and biogeochemical cycles, in particular those of carbon and nitrogen (Dunn et al. 1999; Fu et al. 1999; Withers and Dil 1999). Furthermore, such changes can leads to soil loss and degradation, including the migration of soil nutrients to surface waters (Guo et al. 2001) and shifting of the soil atmosphere carbon balance (Wang and Zhou 1999; Jin et al. 2001).

Ecosystem destruction by quarrying activities, such as coal mining and limestone extraction create significant impact and degradation problems because of soil depletion and alteration in the original topography. Removal of vegetation induces a very high risk of soil erosion in these areas (Clemente et al. 2004). All these will lead to accelerated erosion of biological diversity and creation of several other environmental problems (Singh et al. 2002). The situation is particularly alarming in tropical areas where loss of forest and degradation of land, that earlier supported forest, are being destroyed at unprecedented rates (Parrotta et al. 1997). As the utilization of natural resources continues and opportunities to restore ecosystems damaged by human activities become more common, restoration is playing an increasingly important role in environmental protection (Prach et al. 2001).

In recent years with the extensive use of minerals, domestic and international demands have increased. Moreover, with the economic development of mountain areas to eliminate poverty, rare-earth mining is developing rapidly (Pensa et al. 2004; Walker et al. 2004). Though extraction of minerals is essential for developmental activities, however, this has led to a series of environmental problems such as forest destruction, soil and water loss, and environmental pollution, which will result in reduced biodiversity (Xu and Liu 1999; Yang 1999). The terrestrial and aquatic ecosystems adjoining the mines become adversely contaminated leading to loss of biodiversity and depletion of other natural resources. All such environmental perturbations exert tremendous pressure on human health and socio-economic fabric of the society. These in turn, have multifaceted repercussion at local, regional and global level (Singh 2005).

The environmental impacts of mining operations commence with exploration activities, extend through extraction and processing of minerals, and may continue with post closure of the operation, where the nature and extent of impacts vary throughout the stages in mining operation. Large scale denudation of forest cover and depletion of biodiversity, scarcity of water, pollution of air, water and soil, and degradation of agricultural lands are some of the serious environmental implications of mining (Mishra et al. 2005). Besides, caving in of the ground, subsidence of land and haphazard dumping of minerals and overburden, deteriorate the aesthetic beauty of the landscape and leave scars on the face of the earth (Chaulya 2004).

The mineral extraction processes drastically alters the physical and biological nature of a mined area (Corbett et al. 1996). As a result of mining, significant areas of land are degraded and undesirable waste materials in the form of dumps and tailings replace existing ecosystems around the world (Kleiv and Sandvik 2000). Moreover, tailings are almost completely devoid of vegetation due to toxic level of heavy metals and other unfavorable edaphic conditions. The bare surfaces of tailings are susceptible to wind and water erosion and act as a continuous source of metal contamination to the surroundings (Shu et al. 2005; Tordoff et al. 2000). In addition, the common method of mining increases drainage and the physical and chemical erosion of the substrate, hindering natural germination and establishment of young plants, thus delaying recolonization (Sort and Alcaniz 1996). Degradation of aquatic ecosystems and receiving water bodies, often involving substantial reduction in water quality, can be among the most severe impacts of mining.

Water draining from mining areas are often seriously affected by run-off from operating and abandoned mine workings. Effluents typically consists of acid mine drainage (AMD), eroded material from mine tailing deposits and waste from ore processing operations (Salomons 1995). AMD is a result of complex and interactive suit of physical, chemical and biological processes operating within the waste material. The major factors controlling the rate of oxidation include:

- pH,
- acid neutralizing capacity,
- temperature,
- concentration and reactivity of redox species,
- oxygen availability,
- concentration of carbon dioxide,
- nutrient requirements,
- sulphide mineralogy and particle size,
- galvanic interactions,
- hydrogeology.

AMD is evolved from reduced sulfur materials that have been oxidized on exposure to water and oxygen, and a process often brought about through mining activities (Hallberg et al. 2005). In a large proportion of the literature, AMD is summarized by a chemical equation giving the reader the impression that it is a pure inorganic process. However, numerous publications have shown that in a sterilized sample of the waste material there is hardly any leaching of metals at all unless other oxidizing agents, other than bacteria, are present like ferric iron. The role of bacteria and chemical processes in the dissolution of sulphide minerals has been summarized by Singer and Stumm (1970) for oxidation of pyrite.

$$FeS_2(s) + {}^{7}/_{2}\,O_2 + H_2O \xrightarrow{\text{microbially}} Fe^{2+} + 2H^{+} + 2SO^{2-}_{4}, \qquad (1)$$

$$2Fe^{2+} + \tfrac{1}{2}\,O_2 + 2H^{+} \xrightarrow{\text{microbially}} 2Fe^{3+} + H_2O, \qquad (2)$$

$$FeS_2(s) + 14Fe^{3+} + 8\,H_2O \xrightarrow{\text{Chemically}} 15Fe^{2+} + 2SO^{2-}_{4} + 16H^{+}, \qquad (3)$$

$$Fe^{3+} + 3H_2O \xrightarrow{\text{Chemically}} Fe(OH)_3(s) + 3H^{+}. \qquad (4)$$

Attempts to demonstrate that microbial action duplicated by ferric iron alone have not been definitive, and have led to the suggestions that both direct and indirect bacterial action may be operating simultaneously (Ehrlich 1990). Apart from iron, other heavy metals are also released since many heavy metals are incorporated in pyrite (FeS_2), and other sulphides can also be leached accordingly. The most active bacteria involved in the leaching of sulphide minerals are *Thiobacillus thiooxidans*, *Leptospirillum ferrooxidans* and *Acidithiobacillus ferrooxidans* (Bosecker 1997; Kelly and Wood 2000).

The pyrite oxidation reactions produce sulfuric acid and ferric hydroxides and mobilize other trace metals depending on the surrounding mineralogy (Schmidt et al. 2002). These toxic acids and metals flow to surface waters, where the acid is eventually neutralized, causing metals to precipitate and coat streambeds with metal oxides, impairing the habitat and adversely affecting the water quality in rivers (Office of Surface Mining 1995). The biotic effects associated with AMD impact surface waters including acute impairment of aquatic life as a result of low pH and elevated levels of dissolved heavy metals (Henry et al. 1999; Kullberg et al. 1992; Schmidt et al. 2002).

The contamination of soil with trace elements is considered a serious localized problem related to mining activities. Heavy metal contamination from mining activities creates a wide spectrum of hazards under an equally wide spectrum of contexts. Gaseous, particulate, liquid and solid waste discharges into the environment from mines cause soil and water acidification, air, water, soil and plant contamination by trace elements, deterioration of soil biology and fertility, and soil erosion. The environmental concern in mining areas is primarily related to mechanical damage of the landscape, trace elemental pollution and acid mine drainage (Anju and Banerjee 2005).

Historically, mining is next to agriculture, the world's oldest and most important activity. Exploration, extraction and utilization of minerals are important for the economic growth. India is endowed with significant mineral resources distributed all over the country, including the seabeds. In India, the number of mines and the production of minerals have increased substantially (Singh and Vasistha 2004). The total number of mines has increased by 42 per cent and the production of coal, iron, copper, bauxite and limestone has increased by 4, 11, 33 and 16 times, respectively from 1957 - 1985 (Anon 1990). India has an estimated 85 billion tones of mineral reserves remaining to be exploited.

Meghalaya has rich deposits of coal and limestone. The coal deposits occur along the southern fringe of Shillong plateau over a length of 400 km (Coal India 1986). In the hills of Meghalaya, coal bearing sedimentary formation is sub-horizontal to gentle deep in nature. Coal and limestone are mainly found in Khasi Hills, Garo Hills and Jaintia Hills of the state. The total coal reserve of Meghalaya is about 560 million tones. However, limestone deposits are around 5,000 million tones (Mineral Resources 1998), among these 531 tones of limestone has been estimated from the western part of Jaintia Hills, Meghalaya (Ministry of Mines 2006). The total coal and limestone reserves in Jaintia hills have been estimated to be about 40 and 1,050 million tones, respectively. These reserves are mainly situated in Sutnga, Lakadong, Musiang – Lamare, Khliehriat, Ioksi, Ladrymbai, Rymbai, Bapung, Jarain, Shkentalang, Lumshnong and Sakynphor. Coal is embedded in sedimentary rocks, sandstone and shale of the Eocene age. These three types of coal seams vary from 30 to 212 cm in thickness (Guha Roy 1992).

Mining operations in Meghalaya is being done mainly with the most traditional and unscientific methods and have led to massive environmental degradation. It affects the land, water and community health, particularly when the ecological and occupational considerations are not given due importance. Extraction of coal in Jaintia hills is done by primitive mining method commonly known as 'rat-hole' mining. In this method, the land is initially cleared by cutting and removing the ground vegetation, and then pits ranging from 5 – 100 m^2 are dug vertically in the ground to reach the coal seam. Thereafter, horizontal tunnels are made into the seam for extraction of coal, which is brought back to the pit by using a conical basket or a wheelbarrow. The entire process of mining is done manually employing small implements. While digging the pits, the pieces of soil and rocks above the coal seams are thrown haphazardly outside the pit creating coal mine spoils that cause large-scale destruction to the surrounding agricultural cropland and vegetation, often beyond replenishment. The prevailing land ownership system encourages this kind of unscientific mining operation in the area (Lyngdoh et al. 1992; Das Gupta 1999; Swer and Singh 2005).

Jaintia Hills has a large number of /and rivers and streams that drain the undulating landscape of the area and serve as important sources for drinking, irrigation and support a rich array of floral and faunal diversity. Unfortunately, rampant coal mining has adversely affected the quality of water of most water bodies. Acid mine drainage originating from mine and coal spoils, leaching of heavy metals and organic enrichment by various anthropogenic activities are the main sources of water pollution which has serious implications on aquatic life, agricultural activity and availability of potable and irrigation water in the area.

An understanding of the environmental impact of mining on aquatic and terrestrial ecosystem is a prerequisite for effective management practices. Keeping the above facts in view, the present research work intends to study the impact of coal and limestone mining on aquatic and terrestrial ecosystems of Jaintia Hills, Meghalaya. To achieve the above goal, two objectives were framed: (a) to determine the water and soil characteristics affected by coal and limestone mining and (b) to study plant diversity and community characteristics in the mining areas.

Chapter 2

Review of Literature

Of the global land area (13,300 million ha), India with 329 million (2.4% of the total area) is unique in its physical and geographical features. However, improper land use, excessive biomass removal, uncontrolled grazing in open access areas, mining and dumping of waste material have affected 32.67% of the country's area (Raizada et al. 2004). The destruction of ecosystems through mining and other activities to meet industry demands has been an intrinsic part of modern development. Continued exploitation of natural resources due to anthropogenic activities has resulted in the depletion of forest cover, loss of biodiversity and land degradation all over the world.

Mineral processing occupies a large land area around the world (Shu et al. 2005). Mining of mineral resources either by open cast or underground methods has serious implications on environmental security if proper management strategies are not adopted (Singh and Vasistha 2004). Singh et al. (1999) suggested that open cast coal mining is very common in India and results in the dumping of very large amounts of overburden of mine spoil on unmined land. Dadhwal (1999) pointed out that the unscientific mining of minerals poses a serious threat to the environment. The adverse impact of surface mining is generally much greater than that of underground mining. Removal of overburden and its subsequent placement creates major changes in the topography, hydrology, and stability of the landscape (Bell 1991). Land degradation by open cast - mining clearly falls into the category of severely degraded, an area ready for rehabilitation (Mulligan et al. 1999).

The most severe impact of mining on biodiversity is the removal of vegetation and canopy cover, which may result in habitat fragmentation. Plant communities, which occur naturally are disturbed by mining activity and become impoverished because mining environment alters the natural conditions and provides a very harsh condition for plant growth (Sarma 2002). Various workers in different parts of the world have conducted studies related to floristic composition of the mining areas. Rodrigue (2001) studied the woody species diversity, forest productivity, stumpage value and carbon sequestration of mining areas of Virginia. Pensa and his coworkers (2004) have analyzed the vegetation in opencast mines in Estonia and concluded that spontaneous succession promotes establishment of diverse vegetation. Studies conducted by Stearns et al. (2005) on the effect of coal-bed methane discharge water on the vegetation and soil ecosystem in Powder river basin, Wyoming (USA) found that, vegetation analysis indicated greatest species richness occurred in unmined areas compared to the mine affected sites.

Mining operation has a major impact on the environment. Hutchison and Ellison (1992) presented evidence of the cost sensitivity of mining operations to changes in environmental regulation in California. Roy Waller Associates (1992) studied the impact of mineral extraction and its ultimate form of land degradation in Britain. The native plant communities are disturbed by mining activity because the mining environment alters the climatic and edaphic complexes of the plant communities leading to a drastic reduction in plant growth. Holl (2002) studied long term vegetation recovery on reclaimed coal surface mines in the eastern USA and suggested that coal surface mines can recover diverse native community fairly quickly, if appropriate site conditions are present.

Past research in abandoned mines (Bradshaw 1984; Myster and Pickett 1990; Myster 1993; Champers et al. 1994) demonstrated that vegetation composition at the time of abandonment strongly influences successional trajectories. Connell and Slatyer (1977) hypothesized that initial vegetation may facilitate, tolerate or inhibit establishment of later successional vegetation. Callaway and Walker (1997) have argued that there is a tendency towards facilitation in natural recovery of highly degraded system, such as abandoned mines. Many mine reclamation efforts focus on establishing rapid growing non-native species that control erosion but may compete with later-successional, native species (Holl 2002). A number of authors have suggested that these intensive reclamation efforts may inhibit long-term ecosystem recovery (Champers et al. 1994; Holl and Cairns 1994; Allen et al. 2001) but less research has been done to test these hypotheses, due to time constrain, since most reclamation projects were of short durations (Holl 2002).

The studies related to floristic composition to of the mining areas have been conducted by various workers in different parts of the world. Batty (2005) studied the potential importance of mine sites for supporting rare and threatened species, and highlighted the importance of these species in the remediation of polluted environments. Stearns et al. (2005) studied the effect of coal-bed methane (CBM) discharge waters on the vegetation and soil ecosystems in Powder River Basin, Wyoming and documented that the native vegetation species density was highest at the reference and CBM affected upland sites and the affected site had the greatest percent composition of introduced vegetation species. They also suggested that the salt-tolerant species had the greatest richness at the affected gully, implying a potential threat of invasion and competition to established native vegetation.

Day (1993) found that limestone areas are particularly valuable sources of minerals and rich agricultural land, and for this reason have become increasingly vulnerable to human activity. Brewer et al. (2003) studied the effects of different topographic positions on the composition, phytogeography and diversity of tree species in limestone area of southern Belize and suggested that future decision about the delimitation and management of protected areas in this region will require a better understanding of the patterns and composition of the biodiversity of limestone forests.

Establishment of woody species in degraded lands is highly variable due to the many stochastic factors that affect vegetation succession (Pensa et al. 2004). Promoting spontaneous succession for ecological restoration therefore requires careful considerations of the target ecosystem and time scale in which the goals of restoration are to be achieved (Prach 1994; Prach and Pysek 1994, 2001; Prach et al. 2001; Pysek et al. 2001). If the goal is to restore a certain type of plant community, an engineered restoration process is preferred and succession should be directed toward intended objectives. When selecting suitable tree species for plantations, variable results rendered by different species under the same environmental conditions must be borne in mind (Singh et al. 2002; Jeeva 2003). For example, Montagnini et al. (1995) showed that among 20 indigenous tree species used for reclaiming forests on degraded lands in Brazil, four species tended to have more positive effects on soil properties than others. On abandoned agricultural lands in India restored with different bamboo species, the diversity of ground vegetation was greatest under the canopy of a specific species (Arunachalam and Arunachalam 2002).

Various workers have considerably studied the factors that contribute to the early colonization of mine dumps. Sort and Alcaniz (1996) mentioned that the quarrying exploitation in terraces increases drainage and the physical and chemical erosion of the substrate, hindering natural germination and establishment of young plants, thus delaying recolonizaton. Clemente et al. (2004) recommended that revegetation programs should be conduct by using native species, because increasing the number of plant species would create an array of microsite conditions available for colonization by other species and also mimic the natural vegetation, accelerating secondary succession.

Singh and Singh (1999) found that natural succession on coalmine spoils is a slow process due to surface mining that alters the physico-chemical property of soil. The study of natural forest succession showed that degraded lands can be developed into closed-canopy secondary forest through natural succession in the absence of disturbance, in about 30 – 40 years (Zhuang 1993), the time span on more degraded sites required is, however, longer (Zhuang and Yau 1999).

Metal mining throughout the world has contaminated soils with heavy metals in excess of natural soil background concentrations and introduced metal contaminants into the environment through gaseous and particulate emissions, waste liquids and solid wastes (Dudka and Adriano 1997). Hammarstrom et al. (2003) have mentioned that weathering can produce positive – negative impacts on ecosystems via sequestration and release of metals and acidity.

Destruction of soil property causes reduced soil productivity. Mine spoils present very poor condition for plant growth because of low nutrient contents, either coarse structure or compacted structure (Dutta and Agrawal 2000). Pederson et al. (1988) observed that the surface material from coal mining in Pennsylvania had a high density and low porosity resulting in low filtration rates. Agrawal et al. (1993) reported that the high temperature and low moisture content in surface coalmine spoils are important factors that limit plant growth. Plants act as the principal entry points of heavy metals into the food chain leading to harmful effects on animals and man (Rauser 1990).

It has been demonstrated that in mine tailings and other contaminated soils, the distribution of the heavy metals is not homogenous. It varies horizontally and with soil depth (Geeson et al. 1998; Haines 2002; Podar et al. 2004; Schwartz et al. 1999; McGrath et al. 2004). Such heterogeneity modifies growth pattern of roots and root morphology, resulting in ecotype-specific root production in soils with heterogeneously distributed heavy metals. Metal-contaminated soils are enriched with different dominance of the various metals (Ernst et al. 2000; Ernst and Nelissen 2000; Walker and Bernal 2004). It strongly affects the productivity of even metal resistant plants because, the resistance to each of the metals is regulated by one to two genes per metal (Ernst 2005).

In addition to soil physical characteristics, the nutrient status of overburden is also a major factor limiting plant growth (Dutta and Agrawal 2002). The cycling of nutrients regulates the sustainability of any plant community. Without cycling, nutrients will be immobilized and the plant community will not be capable of regeneration. Soil physico-chemical characters are crucial to the prediction of plant growth potential in mine overburdens, with water holding capacity and infiltration rate as the other important variables (Jha and Singh 1991; Dutta and Agrawal 2002). This is evident from the fact that the coal mine spoils have a coarse texture and low water holding capacity (Lyngdoh 1995; Dutta and Agrawal 2001).

Harris et al. (1993) and Anderson et al. (2004) discussed that the mining operations cause major damage to whole ecosystem, drastically disturbing soil properties, and adversely affecting or impairing nutrient cycling. Boerner et al. (1998), Hearing et al. (1993) and Palumbo et al. (2004) reported that mined soils are often characterized by high bulk density, low pH, low nutrient availability, poor structure, low water holding capacity, and low biomass productivity. Coyne et al. (1998) studied the gross nitrogen transformation rates in soil at a surface coal mine site reclaimed for prime farmland use and noted that the drastic pH changes can adversely affect biotic or living component of the soil, such as fungi, which has symbiotic relationship with plant roots helping in nutrient absorption from the soil. Adverse physical, chemical and biological conditions often limit restoration of surface mine reclamation sites.

Soil is extremely degraded in mining areas and mining operation adversely affects the soil productivity (Srivastava and Singh 1988; Srivastava et al. 1989; Williamson and Johnson 1990; Dutta and Agrawal 2000). A study conducted by Singh and Vasistha (2004) in mining areas of Himalayas found denudation of hill slopes, loss of soil layer and decreased in moisture retention. Sankar et al. (1993) mentioned the high proportion of sand in the mine-damaged sites. The sloppy topography of the coalmine spoils makes the dumps vulnerable to erosion (Dutta 1999).

Soil disturbances leads to loss of C and other important properties in an ecosystem. However, these soils are the ones with high potential to sequester soil organic carbon for a long enough time to off-set fossil fuel emissions for the region (Akala and Lal 2000, 2001).

Studies conducted by Puschenreiter and his group (2001) in metal contaminated soils, found that many mine tailings and metal contaminated soils are poor in major nutrients such as nitrogen and phosphorus. In many laboratory and field experiments, compost is added to the contaminated soil (Bleeker et al. 2002; Bennett et al. 2003) and it was noted that fertilization and compost addition improve~~s~~ plant growth, and can often lower the bioavailable fraction by complexing the metals, thus prolonging the phytoextraction period.

Mining and beneficiation processes generate four major categories of waste, i.e. mine waste, tailings, dump heap leach, and acid mine water which are disposed of in the surrounding waters in a more or less environmentally acceptable manner (Anju and Banerjee 2005). The mine water is the water that infiltrates a mine and must be removed to facilitate mining. Metal smelting and refining processes produce gaseous and particulate matter emissions, wastewater and solid wastes. The emissions of SO_2 from smelters contribute to soil acidity. Adverse environmental impacts from contaminated mining sites include risk to human health, phytotoxicity, contamination of water and soil and ecotoxicity. The elemental contamination and acidification destroys physicochemical properties of the soil, resulting in a permanent reduction in soil fertility (Anju and Banerjee 2005). Leita et al. (1995) found that heavy metals severely affect the growth, morphology and metabolism of microorganisms in bulk soils, through functional disturbance, protein denaturation or destruction of the integrity of cell membranes.

Direct disposal of wastes causes deterioration of water quality and loss of productivity of aquatic bodies (Mishra 1992; Mishra and Tripathi 2001; Mishra and Tripathi 2003). In mining areas, water showed a drastic change in pH, salinity, acidity, and toxic elements, which significantly impact water quality and natural ecosystems, and it has become a serious environmental problem around the world (Dudka and Adriano 1997; van Green et al. 1999). Swer and Singh (2004) studied the deposition of silt at the bottom of rivers and streams flowing in mine areas of Jaintia hills, Meghalaya and found that siltation due to mining severely affects the water quality.

Acid mine drainage is the greatest environmental problems of coal mining industry, and the main source of water pollution in and around mining areas (Singh 2005a). Adams et al. (2007) studied the AMD originating from the abandoned pyrite mine of Davis mine site, United states and found that the mine water typically has a pH of 2.9. Nath and Ahmed (2005) have studied the pH of the mining water in Bapung coalfield in Meghalaya and recorded the same trend.

Heavy metal contamination of water caused by mining activities is one of the major environmental problems (Helmisaari et al. 1995; Reedy and Prasad 1990). Recent studies on the impact of AMD have been reported in Australia (Jeffree et al. 2001), England (Hunt and Howard 1994, Hamilton et al. 1999), Ireland (Gray 1998), New Zealand

(Webster et al. 1998; van Geen et al. 1999; Sabater et al. 2003), Spain (Achterberg et al. 1999, 2003; Elbaz-Poulichet and Dupuy 1999; Elbaz-Poulichet et al. 1999, 2000, 2001), Tasmania (Featherstone and O'Grady 1997), USA (Bigham et al. 1990), Wales (Boult et al. 1994), Germany (Beulker et al. 2003; Nixdorf et al. 2003), Korea (Jung 2001; Jung et al. 2002; Lee et al. 2001; Lee et al. 2005) and India (Mishra et al. 2005).

Gray (1998) studied the impact of AMD on lotic ecosystem and found that polluted effluents from acid mines are complex and characterized by elevated concentration of iron and sulphate, low pH, and elevated concentrations of a wide variety of metals depending on the host geology. Boult et al. (1994) have studied the metal transport in a stream polluted by AMD in Anglessy and documented the oxidation by chemical and microbial processes of sulphide minerals after exposure of previously buried material to air and water.

Investigations have been made on the extent of heavy metal pollution on surface water, ground water, soil, air and vegetation by mining and associated industrial activities, particularly thermal power plants and opencast coalmine (Swaine 1990; Kabata-Pendias 1995; Rupper et al. 1996; Benvenuti et al. 1997; Sahu 1998; Gulec et al. 2001; Liorens et al. 2001; Mohanty et al. 2001; Coulthard and Macklin 2003; Fang et al. 2003). Metal pollution by mining and associated industrial activities is mitigated today by strict implementation of clean technology and environmental measures. However, metals released previously by such activities have been retained in the sediments and soils, and still contaminate surface and ground water resources (Khan et al. 2005).

Mining operations alter ecosystems structure and function, hence remediation practices are considered as a prerequisite in mining areas. Chatterjee and Bose (2005) launched the reclamation programme in Jharia coalfield. Moghe (2005) suggested that the ecological amelioration process in abandoned mines should reflect conservation concerns, and it is also important that research should evaluate ameliorative measures based on ecological and socio-economic parameters. Thus, it should have focus on impacts of the landscape transformation on both, human and wildlife. He also suggested that the ecological restoration should be looked at as a tool for replenishing depleted natural resources in the mined out areas, thus achieving a shared goal of restoration of biological communities as well as restoration of livelihoods of the communities affected by mining.

Aravamudhan (2005) has specified the technological strategies for effective and safe mining activities, and suggested that technological strategies can bring about confidence among those concerned with resource management, and enable them to look for effective scientific methods and technical assistance in minimizing the environmental degradations and reducing the consequential hazards.

The pilot scale studies on neutralization of AMD by using limestone were conducted by Maree et al. (1992; 1998; 1999), Maree and du Plessis (1994) and Adams et al. (2007) in various parts of the world. Maree et al. (2004a) has designed the criteria for limestone neutralization in nickel mine and determined that the powdered $CaCO_3$ can be slurried to a constant density and can then be used to treat acid mine drainage. They also found that coal mine effluent mixed with limestone effluent can be used to decrease metals and sulphate concentration.

The reclamation act SMCRA, 1977 requires vegetation to be reestablished on mined soils and that revegetation become self-sustaining. Restoration of vegetation on reclaimed mine soil is difficult because these soils contain toxic materials, low in nutrient contents and plant available water reserves. Selecting right species of plants suitable to the soil and environment of reclaimed mine soil ecosystem is the first requirement for the success of the revegetation program. Many studies have been conducted to determine adoption of plant species for revegetation of disturbed soil in the United States (Gardiner 1993; Wali 1999), France (Hery et al. 2005), South Africa (Blignaut and Milton 2005), Australia (Krauss and Koch 2004), Portugal (Bleeker et al. 2002), China (Ye et al. 2000), India (Dutta and Agrawal 2003; Kumar et al. 2005) and other countries.

Hao et al. (2004) recommended that the ryegrass (*Lolium perenne* L.) is tolerant to Cu toxicity and is suitable for metal mine tailings. Dutta and Agrawal (2003) suggested that on the basis of biomass and primary productivity, hybrid of *Eucalyptus* and *Acacia auriculiformis* are suitable for plantation on coalmine spoil land.

On the contrary, overburden from limestone extraction makes the water basic in nature. Unscientific extraction of limestone adds a new dimension to land degradation followed by water pollution. Thus, water pollution problems in Jaintia Hills are largely due to coal mining and extraction of limestone (Laloo et al. 2005).

Chapter 3

Study site, Soil and Climate

Jaintia hills district occupies the eastern part of the state of Meghalaya. It covers an area of 3819 Km^2, which is 17.03% of the total geographical area of the state and forms a contiguous part of the Khasi Hills consisting of northern undulating hills. The region is predominantly composed of sandstone with clay, coal seams and fossiliferous limestone and is also formed of various rock types with varying lithological characters. Different agents of denudation like rainfall, surface water and temperate conditions have played an important role on the rock types in moulding the landforms of the area.

Jaintia Hills is the eastern part of the Meghalaya plateau, *abode of clouds*, as named by Prof. S.P. Chatterjee in 1932. Geologically, it is a detached part of the Peninsular India. It is separated by the Malda gap, which resulted from the erosion of the river Ganga and the Brahmaputra. Thus, the landscape evolution of the plateau is closely linked with the Indian peninsula and its landscape story consists of different types of erosion, sedimentation, folding, intrusions, movements of land and sea emissions. The core of the plateau is an ancient mass of genesis, schists and granite, which have been exposed in the north but hidden in the south beneath cretaceous and tertiary deposits and the Mesozoic trap known as Sylhet traps. The whole plateau was under sub-aerial erosion from the Cambrian to the Jurassic period. It contains within its face, the mark peneplaination, which ranges from pre-cambrian to recent and sub-recent periods.

gneis?

Description of the Study Site

The present study was conducted in Sutnga Elaka of Jaintia Hills, at a distance of ca. 120 km away from Shillong, the capital of Meghalaya. Hillocks and undulating topography characterize the landscape of the area. Coal mining and limestone extraction are the major problem resulting in soil erosion, water pollution and environmental degradation of the area. To study the impact of mining on plant diversity and community structure of aquatic and terrestrial ecosystem, I selected three study sites (Plate 1: A - unmined area, B - coal mining and C - limestone mining area) in Sutnga Elaka of Jaintia Hills, Meghalaya (Figure 1). The unmined area in Jaintia hills is selected as the control, so as to make an assessment of the impact of mining on the area. The physiography of the study site is mentioned in table 1.

Figure 1. Location of Research Sites

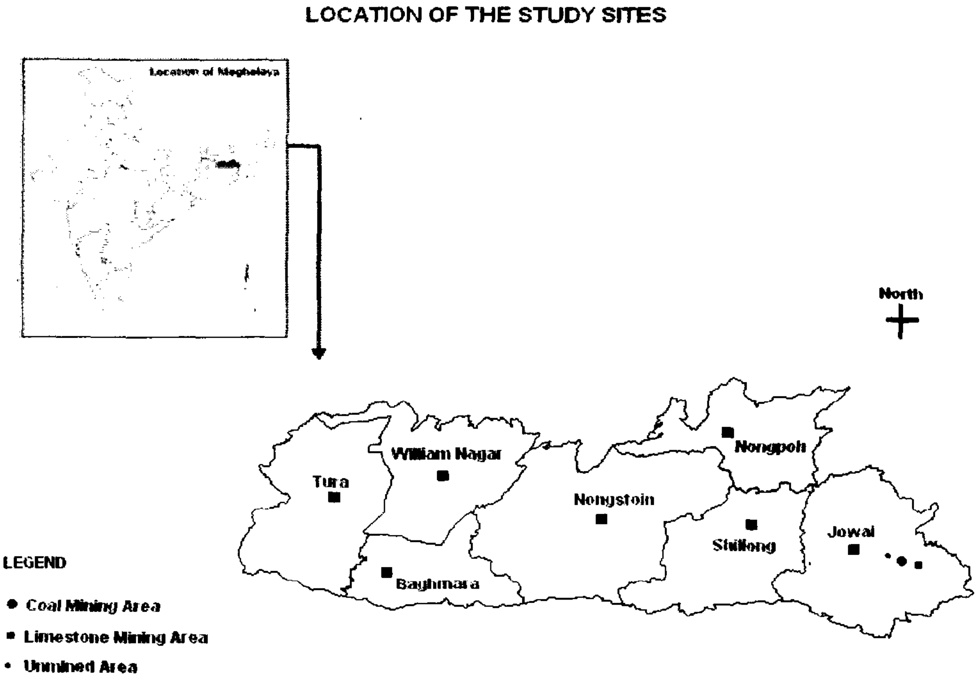
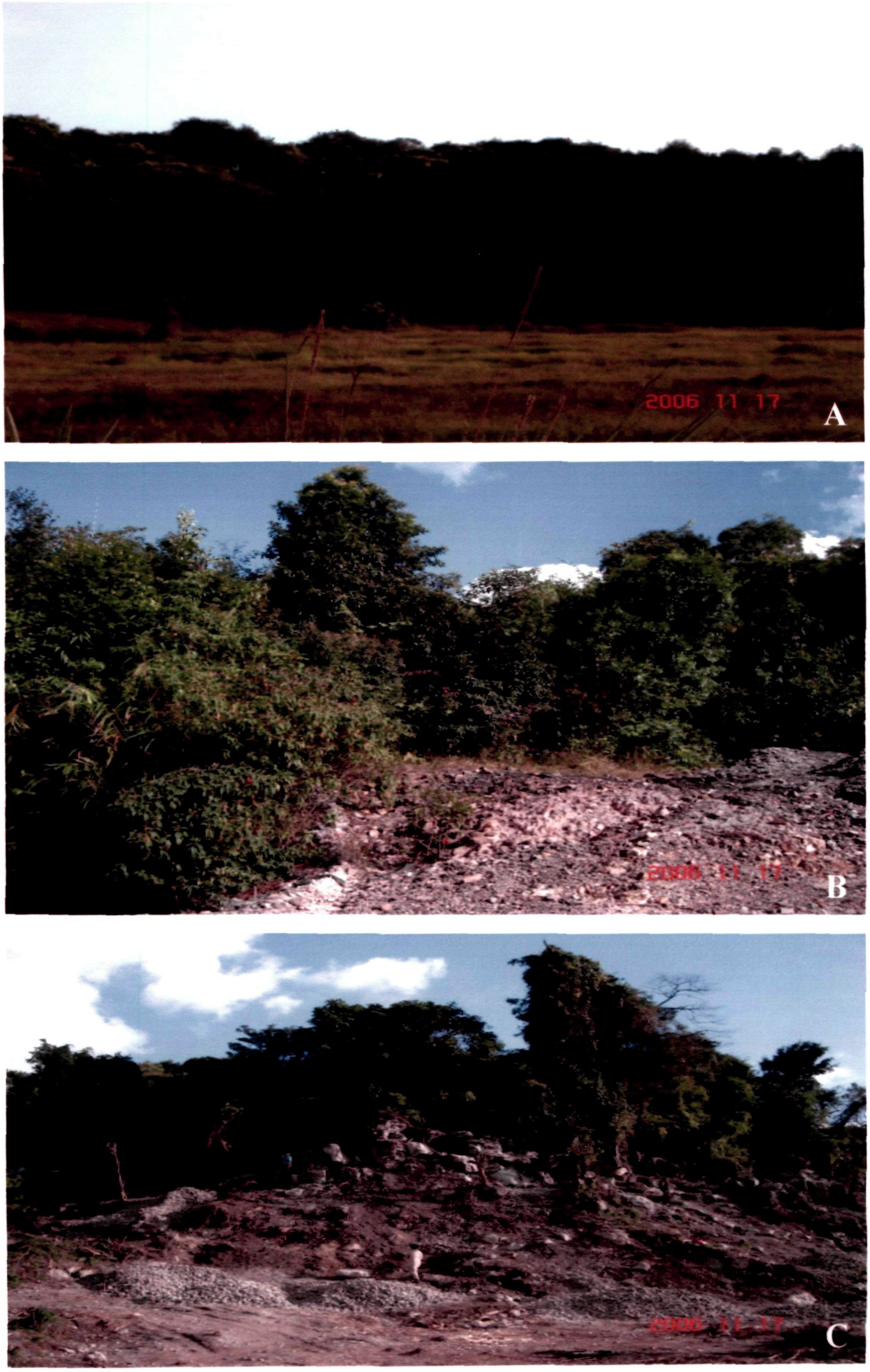


Plate 1. Photograph showing an overview of (A) unmined, (B) coal mining and (C) limestone mining areas of Jaintia Hills, Meghalaya



Soil

The soil is mostly sandy, reddish brown to yellow brown in colour, acidic, rich in mineral content and organic matter, but deficient in phosphate and potash. Such soils are good for the cultivation of banana, potatoes, arecanut, betel vines and hill rice in hill slopes and terraces. Coal and limestone are the major deposits of the soil in the area, which are important raw material for the manufacture of Portland cement.

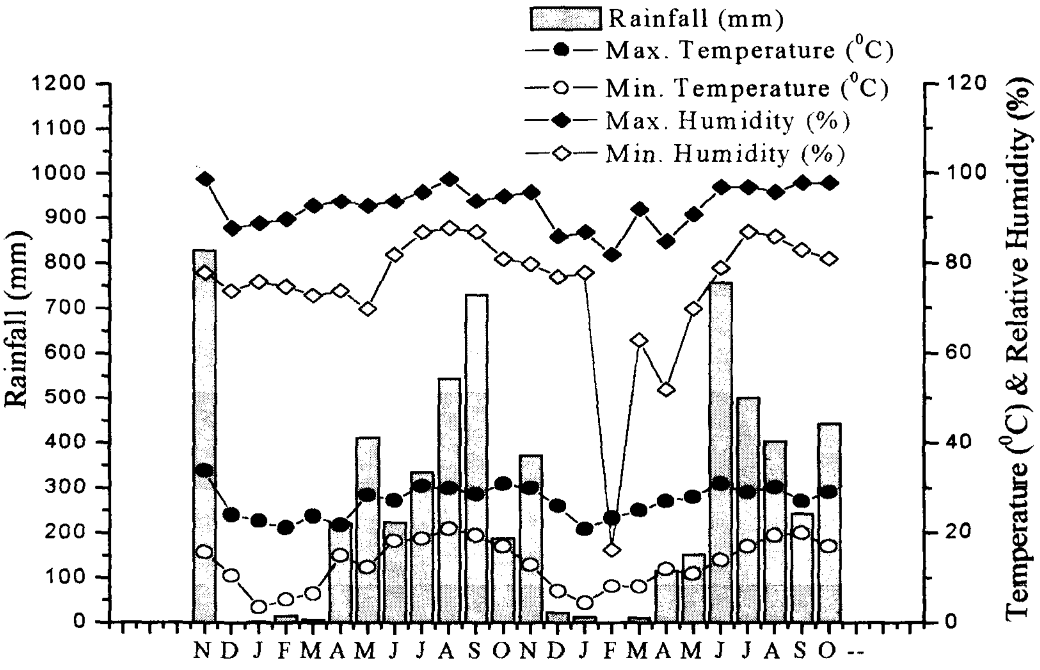
Table 1. Physiography of the study site

Study site	Physiography		
	Latitude	Longitude	Altitude (m)
Unmined Area (Control)	$25^0$20.313'N	$092^0$28.777'E	973
Coal Mining Area	$25^0$21.128'N	$092^0$28.606'E	933
Limestone Mining Area	$25^0$20.552'N	$092^0$29.453'E	995

Climate

The climate of Jaintia Hills is subtropical monsoonic with distinct alternate wet and dry seasons. The wet season extends from April to October, followed by a dry period from November to March. During the wet season the monthly rainfall ranges from 152 to 756 mm, while in the dry period it is usually < 50 mm per month. The mean annual rainfall was 3276 mm during the study period. Relative humidity also exhibited marked seasonal variation and is closely related to precipitation. The mean monthly temperature varied from a maximum of 27^0C in the month of April to a minimum of 3.4^0C in December.

Figure 2. Figure showing the climate of the study area.



Study period 2004 November —2006 October

Vegetation

Depending on rainfall and altitude, Jaintia Hills is clad with a variety of tropical and temperate vegetation. The large-scale unscientific land use practices have resulted in the depletion of primary forest and colonization of the degraded sites by pine forests. The primary forest consists of *Aesculus assamica, Castanopsis indica, Glochidion assamicum, Lithocarpus dealbatus, Myrica esculenta, Quercus glauca, Quercus griffithii,* etc. The endemic and endangered pitcher plant, *Nepenthes khasiana,* is also found in the region. The presence of isolated patches of degraded forests amidst the grassland imparts a savanna like appearance to the landscape of the region. The acidic and highly impoverished shallow soil layer is neither conducive for regeneration through seeds nor for healthy plant growth.

Chapter 4

Impact of Mining on Vegetation

Plants both aquatic and terrestrial are an essential part of a healthy environment; they are a vital part of the biological diversity and an essential resource for human well-being. Plants are the basic component of agriculture, rangeland, forestry and horticulture. In many ways, the welfare of plants is consistent with that of human beings and the environment (Wang et al. 1997).

In recent decades, it has become evident that most of the aquatic and terrestrial ecosystems are changing under increasing pressure from anthropogenic activities (Vitousek et al. 1997; Valiela and Bowen 2002). The environmental status of Meghalaya has been suffering an accelerated degraded process through unscientific mining activities. This process began in the ca. 1960s and has been more intense in recent years, with destruction of large areas of forests creating a landscape characterized by forest fragments at different successional stages, under strong pressure from humans and with serious problems in preserving biological diversity.

Thus, there is a need to understand how the vegetation and community structure is affected by mining activity, so as to develop appropriate strategy for restoration of such areas. Furthermore, the vegetation close to the mining areas are important sources of seeds and are, therefore, definers of the floristic composition and natural regeneration structure. Thus, these patches of vegetation should be preserved and monitored in the plan of action to exploit natural resources (Rodrigues et al. 2004).

This chapter will discuss (i) the impacts of mining on plant diversity and community structure of aquatic and terrestrial ecosystems of Jaintia Hills, Meghalaya and (ii) to find out the suitable native and economically important tree species on the basis of importance value index (IVI) so as to restore the degraded forest areas due to mining. To reach the above goals, I selected three forest sites having surface water bodies namely coal mining, limestone mining and unmined area to study the plant diversity and community structure of aquatic and terrestrial ecosystems of Jaintia Hills, Meghalaya.

Impact of Mining on Aquatic Vegetation

Aquatic plants are relatively short-lived, have rapid response times to many perturbations, are often cosmopolitan in their distributions, and are relatively easily identified (Hill 1997). These plants are significant to the ecology of surface water bodies. Plants form the base of most aquatic food chains, produce oxygen, serve as refuge for aquatic life, and are important in nutrient cycling. Plants interact with their environment through processes that include chemical bio-concentration and excretion, shading, and organic matter production and decomposition (Carpenter and Lodge 1986; Honnell et al. 1993). As a result of these interactions, aquatic plants may significantly affect water quality (Champers and Prepas 1994).

Most aquatic plants have seasonal growth cycles, which are controlled by a variety of ecological factors such as nutrients, light and temperature. The structure and function of aquatic plant communities are influenced directly or indirectly by changes in water quality resulting from the presence of nutrients and phytotoxicants. The input of nutrients and contaminations by anthropogenic activities can inhibit or stimulate plant growth and may cause ecosystem change (Lewis and Wang 1997). Plants have been used frequently as biomonitors where the composition of the plant community has been related to water quality (Seddon 1972; Sculthorpe 1967; Franzen and McFarlane 1980). Plants have also been used as bioremediative agents in water quality management.

Methodology

For studying aquatic plants, 1 × 1m quadrats were laid by using bamboo sticks in the water bodies situated in the coal mining, limestone mining and un-mined area. The plant species (both aquatic and wetlands) were collected and identified by using the national flora, Aquatic and Wetland Plants of India (Cook 1996) and counterchecked with the specimens available in the Botanical Survey of India, Shillong and deposited in the herbarium of Ecology Laboratory, Centre for Advanced Studies in Botany, North – Eastern Hill University, Shillong for future reference.

Results

Altogether, 27 species belonging to 24 genera and 20 families of aquatic plants were recorded from the coal mining and unmined areas (Table 1.1). However, no aquatic plants were recorded in the limestone mining area. This may be due to the presence of high calcium content in the water of the limestone mining area. The total number of plant species found in the mining areas (13 species) was significantly less than unmined areas (20 species).

Table 1.1. Aquatic plants (along with their IVI) present in the mining and unmined areas of Jaintia Hills of Meghalaya

Mining Area		Unmined Area	
Botanical Name	IVI	Botanical Name	IVI
Centella asiatica	13.45	*Alternanthera paronychioides*	6.58
Cyanotis axillaris	6.18	*Aponogeton lakhonensis*	29.84
Cyperus cuspidatus	6.49	*Centella asiatica*	29.3
Fimbristylis aestivalis	7.74	*Colocasia esculenta*	3.29
Fimbristylis dichotoma	3.17	*Cyanotis axillaris*	6.58
Juncus bufonius	10.6	*Cyperus rotundus*	8.77
Limnophila chinensis	96.53	*Eriocaulon echinulatum*	3.56
Polygonum barbatum	22.91	*Houttuynia cordata*	9.31
Polygonum lapathifolium	7.43	*Hydrocotyle sibthorpioides*	5.21
Rotala indica	9.35	*Isachne miliacea*	11.78
Rubus khasianus	6.18	*Juncus bufonius*	9.31
Sagittaria sagittifolia	6.96	*Lindernia mollis*	4.94
Spilanthes calva	3.01	*Lobelia alsinoides*	2.74
		Ludwigia prostrata	15.07
		Murdannia blumei	7.94
		Oldenlandia brachypoda	11.79
		Pandanus fasicularis	3.29
		Polygonum barbatum	11.23
		Rotala indica	16.98
		Spilanthes calva	2.47

In unmined area, Apiaceae and Commelinaceae was the dominant family having two species each. Cyperaceae and Polygonaceae with 3 and 2 species respectively, were dominant and co-dominant families in coal mining area. The number of families represented by a single species was higher in unmined area (16) than mined area (8). Generic composition had depicted that the similar trend was observed in control site, but in the mining area, the family Cyperaceae was the dominant family having two genus (Table 1.2).

Table 1.2. Family wise distribution of aquatic plants in the study area

Mined Area			Unmined Area		
Family	Genus	Species	Family	Genus	Species
Cyperaceae	2	3	Commelinaceae	2	2
Polygonaceae	1	2	Apiaceae	2	2
Apiaceae	1	1	Scrophulariaceae	1	1
Commelinaceae	1	1	Saururaceae	1	1
Juncaceae	1	1	Rubiaceae	1	1
Scrophulariaceae	1	1	Polygonaceae	1	1
Lythraceae	1	1	Poaceae	1	1
Rosaceae	1	1	Pandanaceae	1	1
Alismataceae	1	1	Onagraceae	1	1
Asteraceae	1	1	Lythraceae	1	1
			Juncaceae	1	1
			Eriocaulaceae	1	1
			Cyperaceae	1	1
			Campanulaceae	1	1
			Asteraceae	1	1
			Araceae	1	1
			Aponogetanceae	1	1
			Amaranthaceae	1	1

In the control site, *Aponogeton lakhonensis* was the dominant (IVI 29.84) species, however, *Limnophila chinensis* was the dominant (96.40) species in mining site. *Lobelia alsinoides* (IVI 2.74) and *Spilanthes calva* (IVI 3.01) were the least dominant species in control and mining sites, respectively. The Sorensen index of similarity between two study sites calculated was very low (36.4%), and only 6 species were common in both the sites.

During the present study, it was noticed that in one sampling area of the mining site, agricultural wastes from nearby fields discharged into the river and got mixed with acid mine drainage resulting in eutrophication and excessive growth of aquatic macrophytye, *Limnophila chinensis*. The eutrophication process has resulted in changes in the community composition in the aquatic body.

Discussion

The findings of present study revealed that mining adversely affect the plant diversity in the aquatic bodies. Since the study sites had similar edaphoclimatic condition, the differences in species composition could be attributed to the AMD discharges as a result of the mining activities.

It has been argued that the effect of aquatic plants in low pH is dependent upon the buffering capacity of the water. Decline in pH in mining site is one the serious problems associated with coal mining activity. Increasing acidity strongly affects the aquatic vegetation in various ways including the availability of a large number of essential nutrients in the aquatic ecosystem.

From the present study, the IVI of *Limnophila chinensis* is found to be high due to eutrophication in mining areas. Past studies reported that eutrophication plays a major role in changes of community composition in an aquatic ecosystem. In severe cases, there is a dramatic increase in growth of some species, which often results in algal blooms (Lewis and Wang 1997). This is evident with the findings of the present study.

Impact of Mining on Terrestrial Vegetation

Meghalaya has rich natural vegetations, as well as, large reserve of mineral resources. During the last few decades, phenomenal increase in mining, forest conversion to farmland, exploitation through selective harvest, over harvesting of NTFPs and fuel wood extraction are the major mechanisms of forest degradation, changes in the natural community structure and reduction in biodiversity. Disturbance created by these activities influence forest dynamics and tree density at the local and regional scales (Hubbell et al. 1999) and are important in structuring plant communities (Sumina 1994), particularly evident in the changing size class distributions of the most sought after species (Luoga et al. 2004). Plant communities, which occur naturally are disturbed by mining activity and become impoverished because mining environment alters the natural conditions and provides a very rigorous condition for plant growth. In view of this fact, the present study was aimed to see (i) how mining affects the plant diversity and (ii) what are the changes in community attributes due to mining.

Methodology

The field study was conducted in coal mining, limestone mining and un-mined areas of Jaintia Hills, by following the methods as outlined by Misra (1968), Kershaw (1973), Muller-Dombois & Ellenberg (1974). The vegetation analysis was done by quadrat method. In each forest, 20 quadrats were laid randomly for trees (gbh > 20cm) and shrubs (diameter 5cm to 20cm and/or individuals more than 1m height), using quadrats of size 10m × 10m and 5m × 5m, respectively. For seedlings (individuals up to 1m height), 40 quadrats (1m × 1m size) were laid in each forest. The density, frequency, basal area and importance value index (IVI) were computed. The distribution pattern of species was determined by computing Whitford index (Whitford 1948). The dominance-distribution pattern was determined at both the species and family levels. The Shannon diversity index (Shannon and Weaver 1949), Simpson dominance index (Simpson 1949), Evenness index and Whitaker index were determined.

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats of occurrence of a species}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Density (\%)} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}} \times 100$$

Basal cover = Density × Average basal area of individuals of a species

$$\text{Abundance} = \frac{\text{Number of individuals of a species}}{\text{Number of quadrats of occurrences of the species}} \times 100$$

$$\text{Whitford's index} = \frac{\text{Abundance (A)}}{\text{Frequency (F)}} \times 100$$

Species richness index (Margalef 1958) = $S - 1/\ln N$

where, S is the total number of species, N is total number of individuals and ln is log2.

Diversity index (Shannon & Weaver 1949)

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

where, H' is the Shannon–Weiner diversity index, pi is the proportion of IVI of a species i.e. (ni/N).

Dominance index (Simpson 1949)

$$\mathrm{Cd} = \sum_{i=1}^{s} (pi)^2$$

Plants species were identified using regional floras (Balakrishnan 1981 – 83; Haridasan & Rao 1985 – 87; Kanjilal et al. 1934 – 40). Plant specimens were counter-checked with the reference material available at the Botanical Survey of India, Eastern Circle Shillong and herbarium of the Department of Botany, North-Eastern Hill University, Shillong.

Results and Discussion

Floristic Composition and Similarity

Altogether, 283 species belonging to 225 genera and 93 families of plants were recorded from three forests representing unmined, coal mining and limestone mining sites of Meghalaya (Appendix 1). Of these, 112 species belonging to 100 genera and 52 families of plant species are found in unmined sites, 142 plant species belonging to 123 genera and 60 families were recorded in coal mining areas and 147 species belonging to 131 genera and 67 families were inventoried in limestone mining areas. The number of tree species was higher (71 species) in the unmined sites, followed by coal mining area (46 species) and limestone mining area (42 species). However, shrubs and herbaceous species were higher in mining sites compared to the unmined sites (Table 1.3). The Sϕrensen index of similarity between the study sites was calculated to be very low (19.5%), and only 26 species were common in the study sites (Appendix 1).

Table 1.3. Floristic composition in unmined and mining areas of Jaintia Hills

Floristic Composition	Study Sites		
	Unmined Area	Coal Mining Area	Limestone Mining Area
		Trees	
Number of Species	71	46	42
Number of Genera	63	41	39
Number of Families	34	27	26
		Shrubs	
Number of Species	20	40	47
Number of Genera	20	38	44
Number of Families	13	24	28
		Herbs	
Number of Species	21	56	58
Number of Genera	20	50	55
Number of Families	12	26	29

Floristic composition reveals that the presence of less tree species and high understorey species richness in the mining sites shows the disturbance due to mining activity. Presence of high tree species richness and less shrub species in the unmined site is due to the undisturbed condition of the forests. Mishra et al. (2003) reported that disturbance supports species richness and have recorded high species richness in disturbed stand of Swer sacred forests in Meghalaya. A similar result was also noticed by Upadhaya et al. (2003) who recorded 123 woody species from Ialong and Raliang forests in Jaintia hills of Meghalaya. High tree species richness in unmined site is linked with species turnover, colonization and high species richness (Whittaker 1975; Connell 1978).

Distribution and dominance of families

Altogether, 93 families of angiosperms were reported from all the study sites. Fifty-two families represent the unmined site. However, 60 and 67 families were recorded from coal mining and limestone mining areas respectively. Euphorbiaceae was the dominant family in unmined and limestone mining areas with 10 species and 11 species respectively; however Poaceae was the dominant family in coal mining area, and Euphorbiaceae was found to be the codominant family represented by 11 species. Lauraceae and Rubiaceae having 8 species was the codominant family, followed by Araliaceae (6 species) in unmined site. Asteraceae, the codominant family was represented by 10 species followed by Rubiaceae and Verbenaceae (7 species each) in limestone mining area. The number of families having two species was reported high in limestone mining area (12), followed by 9 species in coal mining site and 8 species in unmined sites. Similar trend was also recorded in case of monospecific families. The number of families represented by a single species was higher in limestone mining area (38) than coal mining (33) and unmined sites (32) respectively (Figure 1.1). Family wise distribution of plant families present in the unmined and mining sites of Jaintia Hills are presented in Table 1.4. The high number of monospecific families in the mining sites shows the disturbance in the study sites and requires appropriate measures for conservation. Despite high tree species richness in unmined sites, the number of monospecific families was low. This could be attributed to elimination of some families, which are very sensitive to low level of disturbance.

Figure 1.1. Dominance-distribution pattern of families in unmined and mining sites of Jaintia Hills, Meghalaya

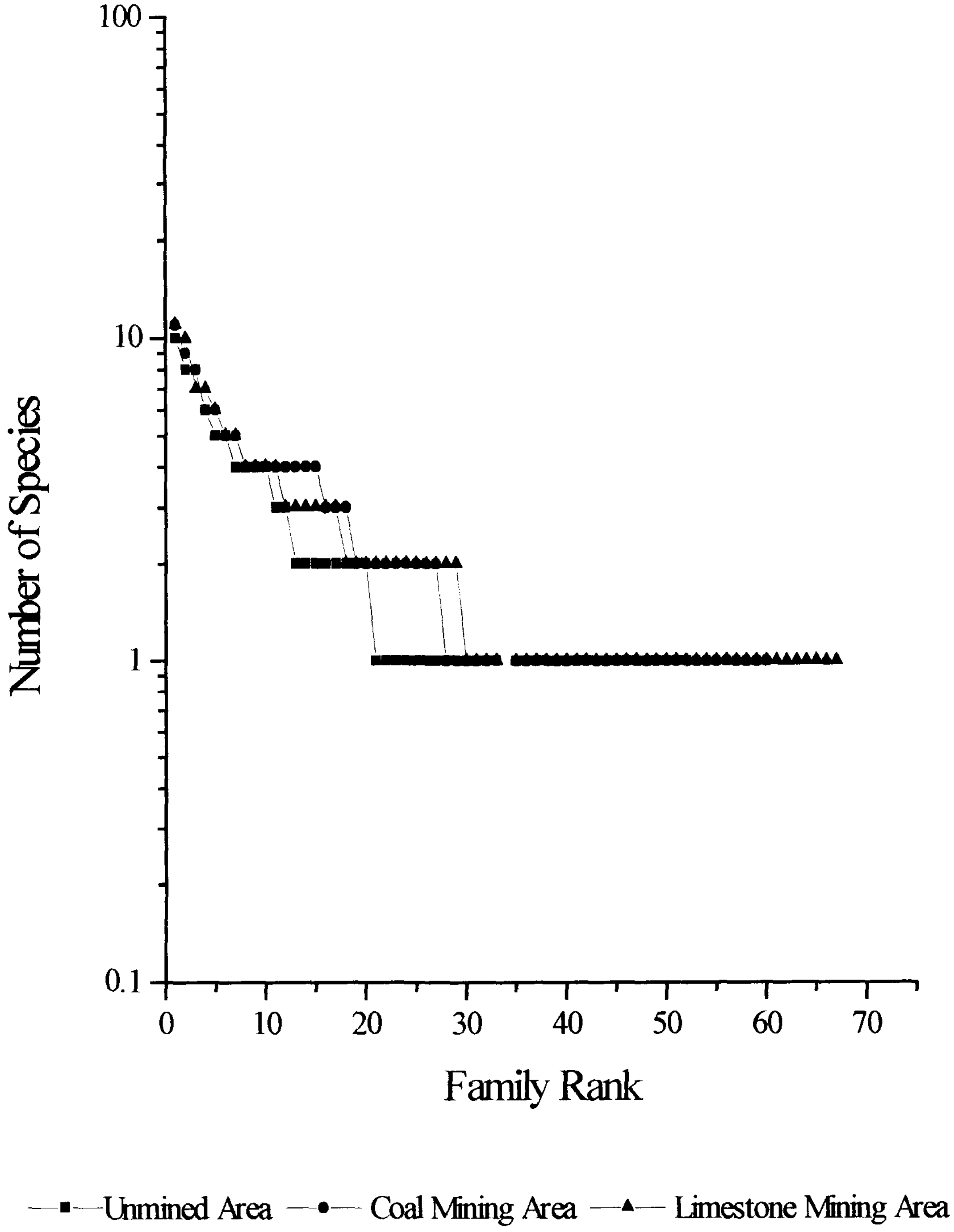


Table 1.4. Species composition of different families recorded from the unmined and mining sites of Jaintia Hills. The families are arranged with respect to family rank based on number of species in a particular family.

Family	Unmined Site		Coal Mining Area		Limestone Mining Area	
Rank	Family	Species	Family	Species	Family	Species
1	Euphorbiaceae	10	Poaceae	11	Euphorbiaceae	11
2	Lauraceae	8	Euphorbiaceae	9	Asteraceae	10
3	Rubiaceae	8	Rubiaceae	8	Rubiaceae	7
4	Araliaceae	6	Lamiaceae	6	Verbenaceae	7
5	Lamiaceae	5	Theaceae	6	Urticaceae	6
6	Theaceae	5	Lauraceae	5	Moraceae	5
7	Fabaceae	4	Verbenaceae	5	Zingiberaceae	5
8	Fagaceae	4	Araliac eae	4	Fabaceae	4
9	Moraceae	4	Asteraceae	4	Lamiaceae	4
10	Sapindaceae	4	Cyperaceae	4	Malvaceae	4
11	Myrsinaceae	3	Fabaceae	4	Poaceae	4
12	Poaceae	3	Fagaceae	4	Amaranthaceae	3
13	Anacardiaceae	2	Melastomataceae	4	Commelinaceae	3
14	Annonaceae	2	Rosaceae	4	Liliaceae	3
15	Begoniaceae	2	Zingiberaceae	4	Meliaceae	3
16	Clusiaceae	2	Begoniaceae	3	Rosaceae	3
17	Meliaceae	2	Moraceae	3	Solanaceae	3
18	Sapotaceae	2	Urticaceae	3	Acanthaceae	2
19	Styracaceae	2	Acanthaceae	2	Anacardiaceae	2
20	Zingiberaceae	2	Annonaceae	2	Apiaceae	2
21	Amaryllidaceae	1	Araceae	2	Araceae	2
22	Berberidaceae	1	Commelinaceae	2	Araliaceae	2
23	Bischofiaceae	1	Malvaceae	2	Campanulaceae	2
24	Campanulaceae	1	Meliaceae	2	Gentianaceae	2
25	Celastraceae	1	Myrsinaceae	2	Lauraceae	2
26	Chloranthaceae	1	Oleaceae	2	Myrsinaceae	2
27	Cyperaceae	1	Polygalaceae	2	Myrtaceae	2
28	Elaeocarpaceae	1	Anacardiaceae	1	Rutaceae	2
29	Ericaceae	1	Apocynaceae	1	Sapindaceae	2
30	Erythroxylaceae	1	Aquifoliaceae	1	Apocynaceae	1
31	Hypoxidaceae	1	Balsaminaceae	1	Arecaceae	1
32	Iteaceae	1	Boraginaceae	1	Balsaminaceae	1
33	Loranthaceae	1	Burseraceae	1	Barringtoniaceae	1

Table 1.4. (Continued)

Family Rank	Unmined Site		Coal Mining Area		Limestone Mining Area	
	Family	Species	Family	Species	Family	Species
34	Magnoliaceae	1	Campanulaceae	1	Berberidaceae	1
35	Malpighiaceae	1	Cannaceae	1	Boraginaceae	1
36	Melastomataceae	1	Caryophyllaceae	1	Burseraceae	1
37	Myricaceae	1	Chloranthaceae	1	Cannaceae	1
38	Myrtaceae	1	Clusiaceae	1	Caprifoliaceae	1
39	Oleaceae	1	Ebenaceae	1	Clusiaceae	1
40	Orchidaceae	1	Erythroxylaceae	1	Cornaceae	1
41	Proteaceae	1	Gentianaceae	1	Cyperaceae	1
42	Rhizophoraceae	1	Liliaceae	1	Dilleniaceae	1
43	Rosaceae	1	Malpighiaceae	1	Elaeocarpaceae	1
44	Rutaceae	1	Mimosaceae	1	Ericaceae	1
45	Sabiaceae	1	Myricaceae	1	Erythroxylaceae	1
46	Saurauiaceae	1	Olacaceae	1	Flacourtiaceae	1
47	Saururaceae	1	Oxalidaceae	1	Hypoxidaceae	1
48	Simaroubaceae	1	Pittosporaceae	1	Leeaceae	1
49	Thymelaeaceae	1	Proteaceae	1	Loganiaceae	1
50	Tiliaceae	1	Sapotaceae	1	Malpighiaceae	1
51	Ulmaceae	1	Saurauiaceae	1	Maranthaceae	1
52	Verbenaceae	1	Saururaceae	1	Melastomataceae	1
53			Scrophulariaceae	1	Olacaceae	1
54			Solanaceae	1	Oleaceae	1
55			Styracaceae	1	Orchidaceae	1
56			Symplocaceae	1	Oxalidaceae	1
57			Taxaceae	1	Plantaginaceae	1
58			Thymelaeaceae	1	Polygalaceae	1
59			Vacciniaceae	1	Polygonaceae	1
60			Violaceae	1	Proteaceae	1
61					Rhamnaceae	1
62					Sabiaceae	1
63					Saurauiaceae	1
64					Saururaceae	1
65					Simaroubaceae	1
66					Styracaceae	1
67					Violaceae	1

Community Characteristics

Density

The total density of the tree species varied considerably between the study sites in relation to mining activity. From the present study, I found high tree density in unmined site (2350 stems ha^{-1}), while 685 and 605 stem ha^{-1} were recorded in coal and limestone mining areas respectively. Tree density is, thus, about three folds higher in unmined sites than in the mining sites. However in case of shrubs and herbs, the reverse trend was observed in terms of density. The low tree species density in case of mining sites depicted due to the mining activities is because of changes in pH, moisture stress and nutrient property of the latter.

Species diversity indices

The species diversity indices varied greatly between the study sites indicating the adverse impact of mining on tree diversity. The Shannon diversity and Whittaker indices was low in mining site than in unmined site. However the reverse trend was observed in case of shrubs and herbs (Table 1.5). The Simpson dominance index was contrary to the Shannon diversity index. The unmined forests had high diversity and low dominance indices. The diversity index of understorey species increase in mining sites suggests that mining operation enhanced the colonization of certain species in the newly created habitats due to mining activities.

Table 1.5. Species diversity indices in unmined and mining sites of Jaintia Hills

Diversity indices	Study Sites		
	Unmined Area	Coal Mining Area	Limestone Mining Area
		Trees	
Shannon	3.41	3.29	3.26
Simpson	0.06	0.07	0.06
Evenness index	0.80	0.86	0.87
Whittaker index	11.54	9.35	8.76
		Shrubs	
Shannon	2.54	3.31	3.46
Simpson	0.11	0.05	0.05
Evenness index	0.85	0.90	0.89
Whittaker index	4.68	8.34	9.13
		Herbs	
Shannon	2.19	3.46	2.31
Simpson	0.19	0.05	0.27
Evenness index	0.72	0.86	0.57
Whittaker index	3.86	8.62	8.10

Dominance

The dominance-distribution pattern at the species and family level justifies the mature, stable and complex nature of vegetation. In the unmined site, *Quercus griffithii* was the dominant (IVI 49.3) species, however, *Schima wallichii* was the dominant (IVI 75.00) species in coal mining area and *Callicarpa arborea* was the dominant species (IVI 58.4) in limestone mining area. *Quercus glauca* was the codominant species in both unmined and coal mining areas having IVI 48.3 and 51.7 respectively. The distribution of IVI among species was more uniform among the species in unmined site (Appendix 1). The dominance-distribution curve followed a log-normal distribution pattern in all the study sites, with short curve in coal mining and limestone mining areas (Figure 1.2).

The dominance-distribution pattern at the tree species level justifies mature, stable and complex nature of vegetation. High tree species content and more even distribution of IVI among the species in unmined site depicts high degree of stability and complexity of community (Mishra et al. 2004, Mishra et al 2005a). It has been argued that ecosystem with high species diversity is more stable and resilient to environmental disturbances than those having low species diversity (Hurd et al. 1971; McNaughton 1977, 1985; Tilman 1988; Frank and McNaughton 1991; Tilman and Downing 1994).

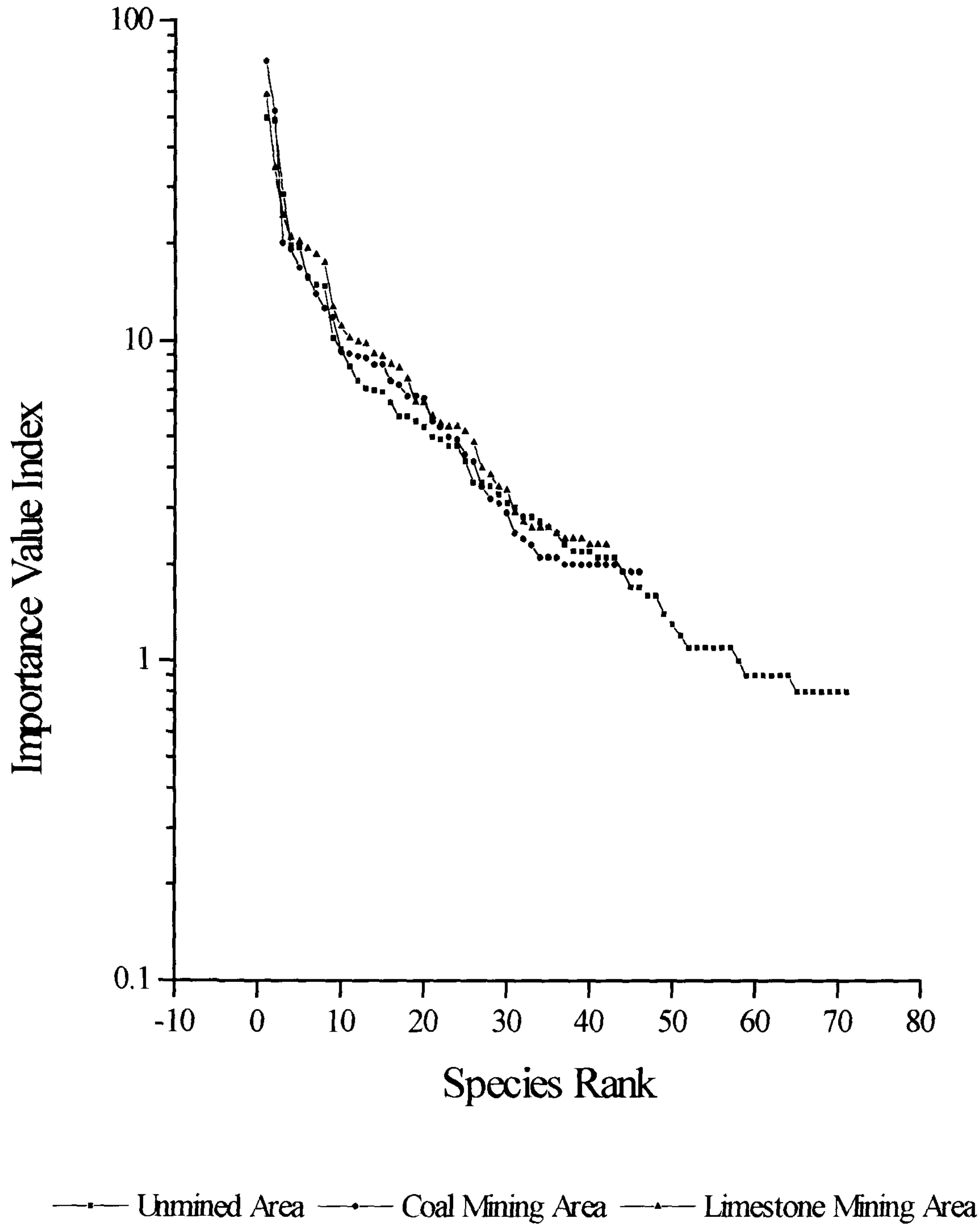
Dominance distribution curves have been used to interpret the dominance of different species in the community in relation to resource appointment and niche space (Whittaker 1975). The curves in the unmined sites (Figure 1.2) resemble the log-normal curve suggesting that there was more or less even apportionment of resources among the members of the important species. The curves for the mining sites resemble the broken-stick series model (Poole 1974). This could be attributed to the lesser number of species occurring in these areas and also represent a stressed environment where conditions were not favorable for plant growth. These sites show low tree diversity, but the species that grow here appear to have developed tolerance that enable them to grow in such an environment (Sharma 2002).

Tree Population Structure

Girth-distribution

Girth class distribution of individuals declined sharply from lower to higher girth classes in all the forests. The trees of low to medium girth classes dominated in all the sites

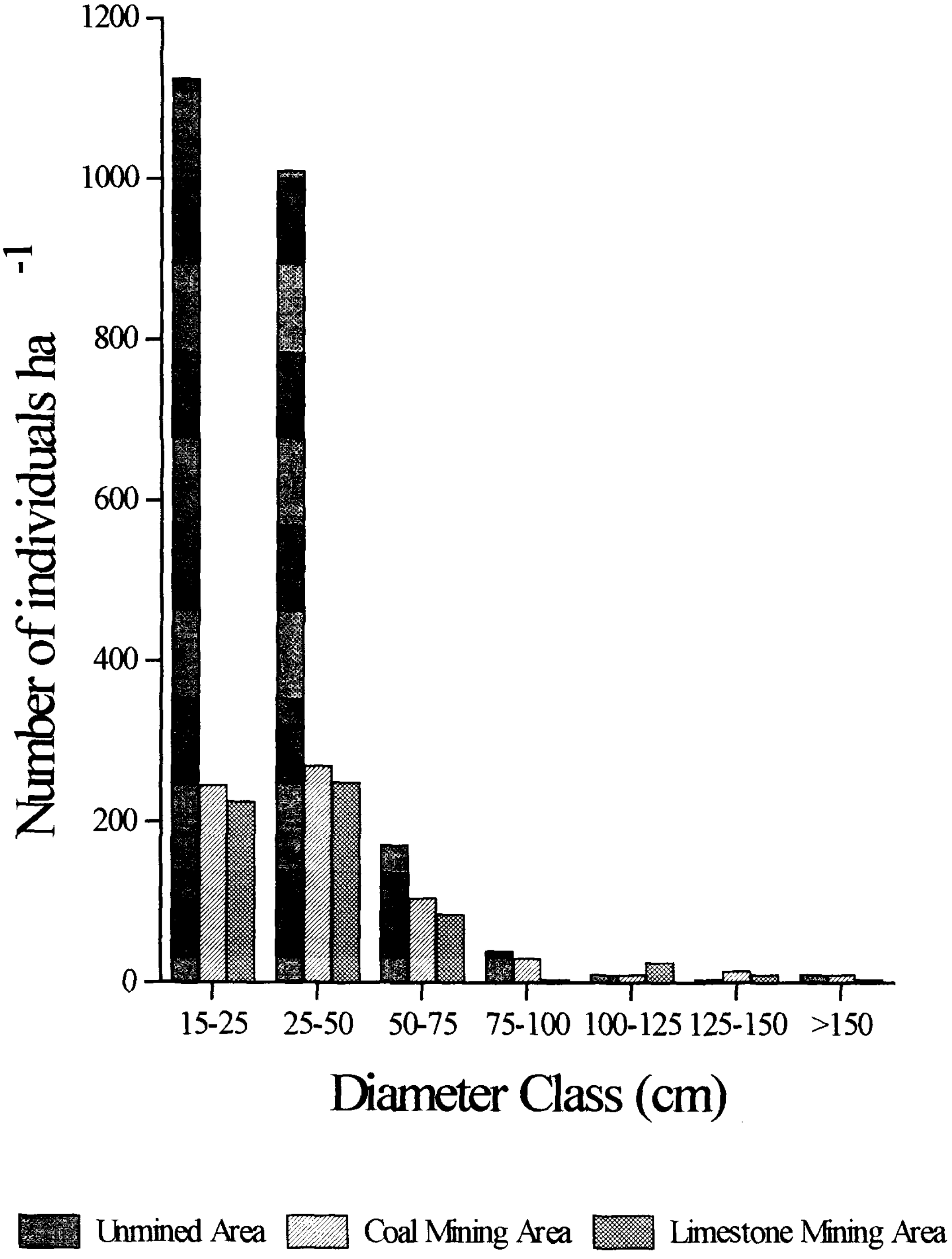
Figure 1.2. Dominance-distribution pattern of tree species in the unmined and mining sites of Jaintia Hills



studied, however in mining sites they were much less in number. The density of trees irrespective of their girth classes was lower in the mining sites than the unmined sites. In the unmined sites, the trees of 15–25 cm (1125 individuals ha^{-1}) and 25–50 cm (1010 individuals ha^{-1}) girth classes dominated the area. However, it was noticed that the tree density was three fold less in mining site than unmined site. The tree density between 15–25 cm girth classes was 245 and 225 individuals ha^{-1} in coal and limestone mining areas respectively, and trees which falls within 25–50 cm girth classes were 270 to 250 in coal and limestone mining areas respectively. The individuals having girth classes 50–70 cm was also found to be high in unmined site (170 individuals ha^{-1}) followed by coal (105 individuals ha^{-1}) and limestone mining (85 individuals ha^{-1}) areas respectively (Figure 1.3).

In the unmined areas, young and middle size trees were higher in number than the old trees indicating stable tree population structure, and is represented by a normal case and suggests that the forest stand is growing and would continue to exist. Girth-distribution follows reverse J shaped curve, which suggests that the forests is climax and stable. However, in the mining sites, the tree density in all the girth classes was extremely low and did not follow any standard density diameter population curve (Rao et al. 1990). This has been due to rampant and random clearing of forest areas for mining activities that have led to the drastic change in tree population structure. Such a trend in population structure does not indicate the continued existence of the forest and requires restoration measures. These forests could be extinct from the environment if appropriate conservation measures are not taken.

Figure 1.3. Girth-distribution of trees (gbh > 15 cm) in the unmined and mining sites of Jaintia Hills



Tree Basal Area

The total basal area of trees in the unmined areas was significantly higher ($P<0.05$) than in the mining areas. Total basal area of the tree species was 50.23, 28.1 and 24.8 (m^2 ha^{-1}) in unmined, coal and limestone mining sites respectively (Figure 1.4).

An extremely low basal area for younger trees in mined sites indicates the removal of younger trees for mining activities. Such a trend in basal area-CBH (Circumference breast height) distribution leads to the failure of the community to regenerate back naturally. Such forest communities could only be restored with management intervention. Similar trends were also observed by Parthasarathi and Karthikeyan (1997) in various disturbed forest stands of Courtallum reserve forest, and Sharma (2002) in mining areas of the Nokrek Biosphere Reserve of Garo Hills, Meghalaya.

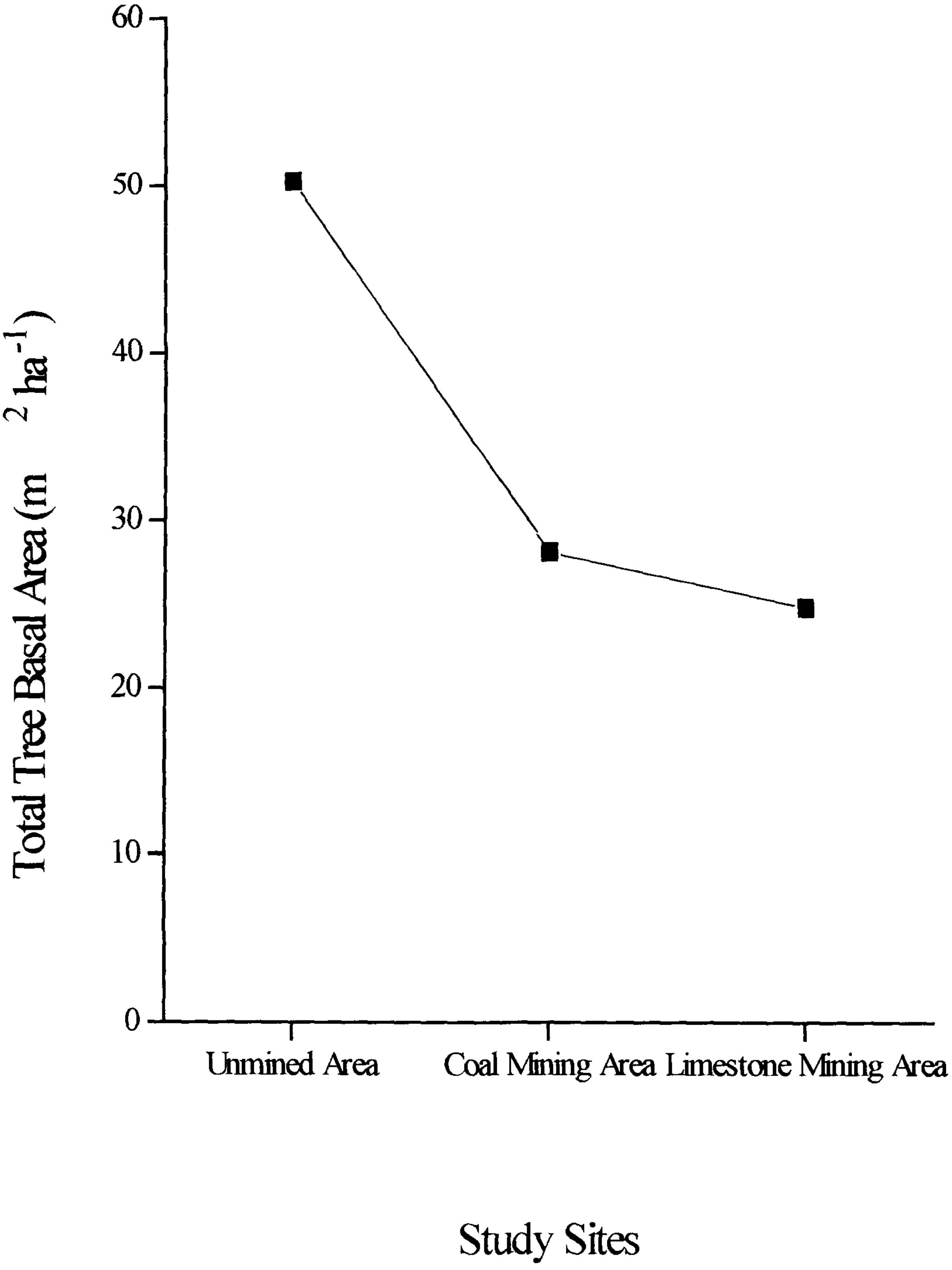
Regeneration Status of Tree Species

Regeneration status of tree species is predicted by the age structure of their populations. Presence of sufficient number of seedlings and saplings in a given population indicates a successful regeneration. Regeneration of tree species is greatly influenced both by biotic and abiotic factors. These factors may affect the recruitment, survival and growth of tree seedlings.

Diversity of Seedlings and Saplings

The unmined areas had significantly higher number of species, both as seedling and saplings, in comparison to mining sites. The seedling and sapling composition of

Figure 1.4. Total tree basal area of trees in the unmined and mining sites of Jaintia Hills



unmined site are 47 and 40 species respectively, while in the coal and limestone mining area they are 20, 17 and 11, 10 species respectively (Figure 1.5). *Lithocarpus dealbatus* (IVI 20.56), *Persea bombycina* (IVI 15.12), *Persea duthiei* (IVI 9.62) and *Quercus griffithii* (IVI 7.17) were the dominant species in unmined area, and *Schima wallichii* (IVI 33.25), *Lithocarpus dealbatus* (IVI 32.58) and *Rhus javanica* (IVI 28.48) were the dominant species in coal mining area, while in limestone mining area *Rhus javanica* (IVI 52.68), *Helicia nilagirica* (IVI 30.54) and *Sarcochlamys pulcherrima* (IVI 27.51) were the dominant species during seedling phase. However, during sapling phase *Itea macrophylla* (IVI 72.84), *Schefflera wallichiana* (IVI 34.71), *Lithocarpus dealbatus* (27.68) and *Persea duthiei* (IVI 26.99) were dominant in unmined site, and *Lithocarpus dealbatus* (IVI 86.23), *Quercus glauca* (IVI 70.34), *Quercus griffithii* (IVI 51.06) and *Rhus acuminata* (IVI 31.96) were dominant in coal mining sites and *Styrax serrulatum* (IVI 137.1), *Alangium chinensis* (IVI 51.91), *Ligustrum robustum* (49.25) and *Callicarpa arborea* (IVI 42.01) were some of the dominant species in limestone mining site.

Density of Seedling and Saplings

The seedlings and saplings densities were also found to be high in unmined site than the coal and limestone mining sites (Table 1.6). The seedling density in the unmined site was 238780 individuals ha^{-1}, while at coal and limestone mining areas it was found to be 75000 and 16500 individuals ha^{-1} respectively. Similar trend was also noticed in case of sapling density. Sapling density was also high in unmined areas (4740 individuals ha^{-1}), than the coal mining area (2520 individuals ha^{-1}) and limestone mining site (1360 individuals ha^{-1}) respectively.

Figure 1.5. Diversity of seedlings and saplings in the unmined and mining sites of Jaintia Hills

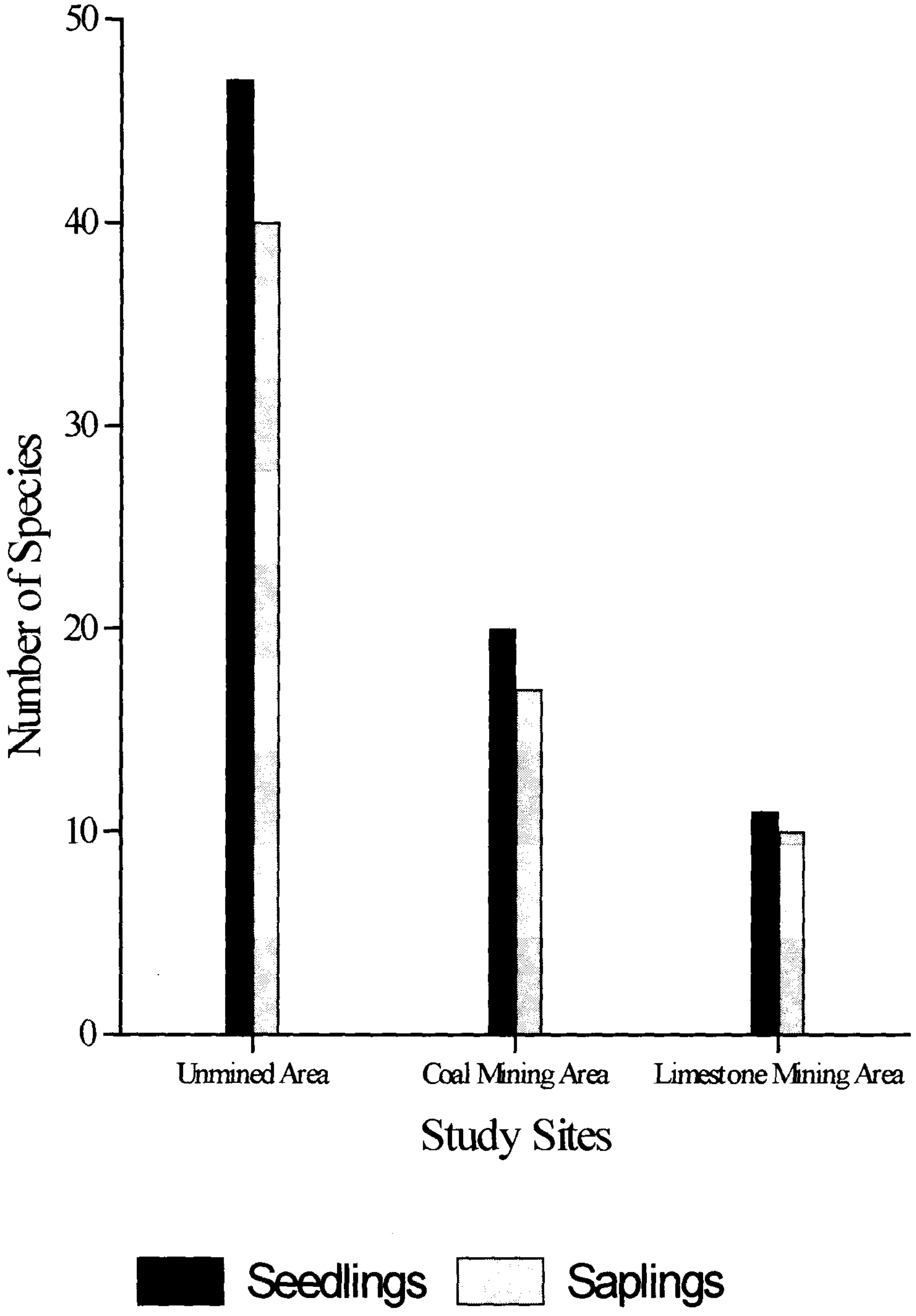


Table 1.6. Seedling and Sapling density (individuals ha^{-1}) in the unmined (UM), coal mining (CM) and limestone mining (LM) sites of Jaintia Hills, Meghalaya

Plant species	Family	UM	CM	LM
Seedlings				
Alangium chinense (Lour.) Harms	Cornaceae	–	–	1000
Aporusa dioica (Roxb.) Muell.-Arg.	Euphorbiaceae	2000	750	–
Aralia dasyphylla Miq.	Araliaceae	4250	–	–
Ardisia griffithii Clarke	Myrsinaceae	13500	–	–
Bischofia javanica Bl.	Bischofiaceae	3250	–	–
Callicarpa arborea Roxb.	Verbenaceae	–	–	2000
Camellia caudata Wall.	Theaceae	6000	2250	–
Celtis cinnamomea Planch.	Ulmaceae	3000	–	–
Cinnamomum glaucescens (Nees) Hand.-Mazz.	Lauraceae	1250	–	–
Cordia dichotoma Forst.f.	Boraginaceae	–	1250	–
Croton joufra Roxb.	Euphorbiaceae	2250	750	–
Cryptocarya amygdalina Nees	Lauraceae	–	2250	–
Dalbergia assamica Benth.	Fabaceae	11000		–
Diospyros kaki Thunb.	Ebenaceae	–	750	–
Eurya acuminata DC.	Theaceae	–	5000	–
Ficus hirta Vahl	Moraceae	–	1000	–
Ficus roxburghii Wall.	Moraceae	2250	–	1000
Ficus semicordata J.E. Smith	Moraceae	4250	–	–
Garcinia pedunculata G.Don.	Clusiaceae	6000	–	–
Glochidion assamicum Hk.f.	Euphorbiaceae	4500	–	750
Grewia multiflora Juss.	Tiliaceae	8250	–	–
Helicia nilagirica Bedd.	Proteaceae	8250	–	2500
Itea macrophylla Wall.	Iteaceae	7500	–	–
Ixora subsessilis G. Don.	Rubiaceae	–	250	–
Ligustrum robustum (Roxb.) Bl.	Oleaceae	11000	–	500
Lindera latifolia Hk.f.	Lauraceae	3250	–	–
Lithocarpus dealbatus (Hk.f. & Th. ex Miq.) Rehder.	Fagaceae	28000	14250	–
Litsea salicifolia (Roxb. ex Nees)Hk.f.	Lauraceae	3250	–	–
Lonicera macrantha (D. Don) Spreng.	Caprifoliaceae		500	–
Macropanax undulatus (G. Don) Seem.	Araliaceae	4000	–	–
Mahonia pycnophylla (Fedde) Takeda	Berberidaceae	6500	–	–
Myrica esculenta Buch.-Ham. ex Don.	Myricaceae	–	7000	–
Myrsine capitellata Wall.	Myrsinaceae	–	2250	–
Persea bombycina (King ex Hk.f.) Kosterm.	Lauraceae	28000	–	–

Table 1.6. (Continued)

Plant species	Family	UM	CM	LM
Persea duthiei (King ex Hk.f.) Kosterm.	Lauraceae	10000	1750	–
Phoebe lanceolata (Nees) Nees	Lauraceae	1250	–	–
Picrasma javanica Bl.	Simaroubaceae	–	–	250
Premna racemosa Wall. ex Sch.	Verbenaceae	–	6000	–
Psychotria symplocifolia Kurz.	Rubiaceae	5250	–	1750
Quercus glauca Thunb.	Fagaceae	14000	–	–
Quercus griffithii Hk.f. & Th. Ex DC.	Fagaceae	12250	2250	–
Randia wallichii Hk.f.	Rubiaceae	6250	–	–
Rhus javanica Linn.	Anacardiaceae	1500	10250	4250
Sarcochlamys pulcherrima Gaud.	Urticaceae	–	–	2000
Saurauia napaulensis DC.	Saurauiaceae	7000	–	–
Schefflera wallichiana (W. & A.) Harms	Araliaceae	6000	–	–
Schima khasiana Dyer	Theaceae	–	1500	–
Schima wallichii (DC.) Korth.	Theaceae	500	14750	–
Styrax serrulatum Roxb.	Styracaceae	–	–	500
Syzygium macrocarpum (Roxb.) Balakr.	Myrtaceae	3250	–	–
Xantolis assamica Clarke.	Sapotaceae	–	250	–
Saplings				
Alangium chinense (Lour.) Harms	Cornaceae	–	–	220
Aporusa dioica (Roxb.) Muell.-Arg.	Euphorbiaceae	40	40	20
Ardisia griffithii Clarke	Myrsinaceae	100	–	–
Artocarpus integra (Thunb.) Merr.	Moraceae	20	–	–
Beilschmiedia brandisii Hook.f.	Lauraceae	40	–	–
Beilschmiedia roxburghiana Nees	Lauraceae	–	80	–
Brassaiopsis glomerulata (Bl.) Regel	Araliaceae	60	–	–
Callicarpa arborea Roxb.	Verbenaceae	–	–	160
Camellia caudata Wall.	Theaceae	120	–	–
Celtis cinnamomea Planch.	Ulmaceae	20	–	–
Dalbergia assamica Benth.	Fabaceae	40	–	–
Derris robusta (DC) Benth.	Fabaceae	40	–	–
Dysoxylum binectariferum Hk.f. et Bedd.	Meliaceae	–	–	40
Dysoxylum gobara (Buch.-Ham.) Merr.	Meliaceae	40	–	–
Eurya acuminata DC.	Theaceae	80	120	–
Ficus hirta Vahl	Moraceae	100	–	–
Ficus semicordata J.E. Smith	Moraceae	80	–	–
Garcinia pedunculata G.Don.	Clusiaceae	160	–	–
Glochidion assamicum Hk.f.	Euphorbiaceae	120	80	–
Grewia multiflora Juss.	Tiliaceae	140	–	–
Helicia nilagirica Bedd.	Proteaceae	20	–	–
Itea macrophylla Wall.	Iteaceae	340	–	–

Table 1.6. (Continued)

Plant species	Family	UM	CM	LM
Ixora subsessilis G. Don.	Rubiaceae	–	80	–
Ligustrum robustum (Roxb.) Bl.	Oleaceae	120	40	200
Lindera latifolia Hk.f.	Lauraceae	60	–	–
Lithocarpus dealbatus (Hk.f. & Th. ex Miq.) Rehder.	Fagaceae	500	460	–
Litsea salicifolia (Roxb. ex Nees)Hk.f.	Lauraceae	100	60	120
Macropanax undulatus (G. Don) Seem.	Araliaceae	180	120	120
Mahonia pycnophylla (Fedde) Takeda	Berberidaceae	160	–	–
Myrica esculenta Buch.-Ham. ex Don.	Myricaceae	–	80	–
Myrsine capitellata Wall.	Myrsinaceae	40	40	–
Persea bombycina (King ex Hk.f.) Kosterm.	Lauraceae	120	–	–
Persea duthiei (King ex Hk.f.) Kosterm.	Lauraceae	340	–	–
Picrasma javanica Bl.	Simaroubaceae	140	–	–
Podocarpus neriifolia D.Don.	Taxaceae	–	40	–
Premna racemosa Wall. ex Sch.	Verbenaceae	20	–	–
Prunus jenkinsii Hk.f.	Rosaceae	–	20	–
Psychotria symplocifolia Kurz.	Rubiaceae	60	–	–
Quercus glauca Thunb.	Fagaceae	340	420	–
Quercus griffithii Hk.f. & Th. Ex DC.	Fagaceae	280	400	–
Randia wallichii Hk.f.	Rubiaceae	100	–	–
Rhus acuminata DC.	Anacardiaceae	60	240	80
Rhus javanica Linn.	Anacardiaceae	–	–	160
Sarcochlamys pulcherrima Gaud.	Urticaceae	–	–	–
Saurauia napaulensis DC.	Saurauiaceae	20	–	–
Schefflera wallichiana (W. & A.) Harms	Araliaceae	260	–	–
Schima khasiana Dyer	Theaceae	–	60	–
Schima wallichii (DC.) Korth.	Theaceae	40	160	–
Styrax serrulatum Roxb.	Styracaceae	–	–	180
Symplocos spicata Roxb.	Symplocaceae	–	–	–
Syzygium macrocarpum (Roxb.) Balakr.	Myrtaceae	140	–	–
Toona ciliata Roem.	Meliaceae	–	–	80
Trevesia palmata (Roxb.) Vis.	Araliaceae	80	–	–
Wendlandia grandis Cowan	Rubiaceae	20	–	–

(– indicates absence of the species)

Better recruitment of seedlings and predominance of individuals in lower girth classes (adults) showed high regeneration efficacy at forest stand level (Mishra et al. 2003; Laloo et al. 2006). Conversion of seedlings into saplings was also found to be high in unmined site. However, low conversion of seedlings into saplings in coal and limestone mining sites could be due to the impact of mining.

Appendix 1

Plant diversity in the unmined (UM), coal mining (CM) and limestone mining (LM) sites of Jaintia Hills, Meghalaya. Values given represent the IVI of the species

Plant species	Family	UM	CM	LM
Tree species				
Acer laevigatum Wall.	Sapindaceae	1.4	–	–
Aesculus assamica Griff.	Sapindaceae	1.1	–	8.9
Alangium chinense (Lour.) Harms	Cornaceae	–	–	8.4
Aphania rubra (Roxb.) Radlk.	Sapindaceae	5.4	–	34.4
Aporusa dioica (Roxb.) Muell.-Arg.	Euphorbiaceae	7.1	2.0	2.9
Aralia dasyphylla Miq.	Araliaceae	4.7	–	–
Ardisia griffithii Clarke	Myrsinaceae	3.3	–	–
Artocarpus integra (Thunb.) Merr.	Moraceae	0.9	–	–
Beilschmiedia brandisii Hook.f.	Lauraceae	4.9	3.5	–
Bischofia javanica Bl.	Bischofiaceae	0.9	–	–
Brassaiopsis glomerulata (Bl.) Regel	Araliaceae	0.8	8.8	–
Bursera serrata Colebr.	Burseraceae	–	6.6	18.6
Callicarpa arborea Roxb.	Verbenaceae	–	14.0	58.4
Camellia caudata Wall.	Theaceae	2.1	2.0	–
Carallia brachiata (Lour.) Merr.	Rhizophoraceae	1.1	–	–
Careya arborea Roxb.	Barringtoniaceae	–	–	6.4
Caryota urens Linn.	Arecaceae	–	–	5.4
Castanopsis indica A. DC.	Fagaceae	0.9	–	–
Celtis cinnamomea Planch.	Ulmaceae	2.7	–	–
Cinnamomum glaucescens (Nees) Hand.-Mazz.	Lauraceae	1.2	–	–
Cordia dichotoma Forst.f.	Boraginaceae	–	4.9	2.4
Croton joufra Roxb.	Euphorbiaceae	10.2	4.2	2.3
Cryptocarya amygdalina Nees	Lauraceae	15.0	5.0	17.6
Dalbergia assamica Benth.	Fabaceae	1.9	–	–
Derris robusta (DC) Benth.	Fabaceae	3.1	–	–
Dillenia pentagyna Roxb.	Dilleniaceae	–	–	5.4
Diospyros kaki Thunb.	Ebenaceae	–	6.7	–
Drypetes assamica (Hk.f.) Pax et Hoffm.	Euphorbiaceae	–	–	9.1
Dysoxylum binectariferum Hk.f. et Bedd.	Meliaceae	–	–	5.8
Dysoxylum gobara (Buch.-Ham.) Merr.	Meliaceae	2.1	6.7	2.3
Echinocarpus dasycarpus Benth.	Elaeocarpaceae	–	–	20.4
Elaeocarpus lancifolius Roxb.	Elaeocarpaceae	2.2	–	–
Erythrina arborescens Roxb.	Fabaceae	–	–	2.6
Eurya acuminata DC.	Theaceae	1.6	7.5	–

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Ficus benjamina Linn.	Moraceae	–	–	19.4
Ficus hirta Vahl	Moraceae	1.7	5.6	–
Ficus roxburghii Wall.	Moraceae	0.8	–	2.4
Ficus semicordata J.E. Smith	Moraceae	2.2	–	–
Garcinia cowa Roxb. ex DC.	Clusiaceae	–	15.8	3.5
Garcinia pedunculata G.Don.	Clusiaceae	19.9	–	–
Garcinia tinctoria (DC.) W.F. Wight	Clusiaceae	1.3	–	–
Glochidion assamicum Hk.f.	Euphorbiaceae	4.7	8.4	3.8
Grewia multiflora Juss.	Tiliaceae	0.9	–	–
Helicia nilagirica Bedd.	Proteaceae	0.8	2.3	8.2
Holarrhena antidysenterica (Roth.)A.DC.	Apocynaceae	–	2.0	–
Hyptianthera stricta (Willd.) W. & A.	Rubiaceae	1.1	–	–
Ilex triflora Bl.	Aquifoliaceae	–	2.5	–
Itea macrophylla Wall.	Iteaceae	19.7	–	–
Ixora subsessilis G. Don.	Rubiaceae	–	11.8	–
Lepisanthes rubiginosa (Roxb.) Leenh.	Sapindaceae	1.6	–	–
Ligustrum confusum Decne	Oleaceae	–	2.0	–
Ligustrum robustum (Roxb.) Bl.	Oleaceae	15.7	12.6	12.7
Lindera latifolia Hk.f.	Lauraceae	7.0	–	–
Lithocarpus dealbatus (Hk.f. & Th. ex Miq.) Rehder.	Fagaceae	28.6	16.9	–
Litsea salicifolia (Roxb. ex Nees)Hk.f.	Lauraceae	3.0	5.4	2.3
Macaranga denticulata (Bl.) Muell.-Arg.	Euphorbiaceaea	0.8	–	–
Macropanax undulatus (G. Don) Seem.	Araliaceae	2.8	8.4	3.4
Mahonia pycnophylla (Fedde) Takeda	Berberidaceae	0.8	–	–
Mallotus tetracoccus (Roxb.) Kurz	Euphorbiaceae	0.8	–	–
Melia dubia Cav.	Meliaceae	–	1.9	–
Meliosma wallichii Hook. f.	Sabiaceae	1.0	–	2.6
Michelia punduana Hook.f. & Th.	Magnoliaceae	1.7	–	–
Microtropis discolor (Wall.) Arn.	Celastraceae	0.9	–	–
Millettia cinerea Benth.	Fabaceae	–	2.4	–
Millettia pachycarpa Benth.	Fabaceae	–	2.1	21.1
Morus macroura Miq.	Moraceae	–	–	–
Myrica esculenta Buch.-Ham. ex Don.	Myricaceae	7.5	20.2	–
Myrsine capitellata Wall.	Myrsinaceae	2.8	3.1	–
Ostodes paniculata Bl.	Euphorbiaceae	–	–	2.5
Pentapanax subcordatus (G. Don) Seem.	Araliaceae	2.1	–	–
Persea bombycina (King ex Hk.f.) Kosterm.	Lauraceae	3.6	–	–
Persea duthiei (King ex Hk.f.) Kosterm.	Lauraceae	4.2	3.2	–

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Phoebe lanceolata (Nees) Nees	Lauraceae	0.9	–	–
Photinia cuspidata (Bertol) Balak.	Rosaceae	–	–	4.0
Photinia integrifolia Lindl.	Rosaceae	–	9.2	–
Picrasma javanica Bl.	Simaroubaceae	2.6	–	5.2
Podocarpus neriifolia D.Don.	Taxaceae	–	1.9	–
Premna racemosa Wall ex Sch.	Verbenaceae	3.5	2.0	2.6
Prunus jenkinsii Hk.f.	Rosaceae	–	2.0	–
Psidium guajava Linn.	Myrtaceae	–	–	4.8
Psychotria symplocifolia Kurz.	Rubiaceae	1.1	–	10.2
Pyrus pashia D. Don	Rosaceae	1.1	–	–
Quercus glauca Thunb.	Fagaceae	48.3	19.4	–
Quercus griffithii Hk.f. & Th. Ex DC.	Fagaceae	49.3	51.7	–
Quercus serrata Thunb.	Fagaceae	–	1.9	–
Randia cochinchinensis (Lour.) Merr.	Rubiaceae	–	–	6.4
Randia wallichii Hk.f.	Rubiaceae	2.5	–	–
Rhus acuminata DC.	Anacardiaceae	5.6	8.9	24.6
Rhus javanica Linn.	Anacardiaceae	6.9	–	11.1
Sarcochlamys pulcherrima Gaud.	Urticaceae	–	–	2.4
Saurauia napaulensis DC.	Saurauiaceae	5.0	2.0	–
Schefflera wallichiana (Wight & Arn.) Harms	Araliaceae	9.4	–	–
Schima khasiana Dyer	Theaceae	–	2.1	–
Schima wallichii (DC.) Korth.	Theaceae	14.8	75.0	–
Stryax hookeri Cl.	Styracaceae	1.1	–	–
Styrax serrulatum Roxb.	Styracaceae	0.8	7.3	7.6
Symplocos spicata Roxb.	Symplocaceae	–	2.1	–
Syzygium cumini (L.) Skeels.	Myrtaceae	–	–	2.7
Syzygium macrocarpum (Roxb.) Balakr.	Myrtaceae	5.8	–	–
Toona ciliata Roem.	Meliaceae	2.2	–	9.8
Trevesia palmata (Roxb.) Vis.	Araliaceae	5.8	4.4	9.9
Wendlandia grandis Cowan	Rubiaceae	8.3	2.9	5.5
Xantolis assamica Clarke.	Sapotaceae	2.3	9.1	–
Xantolis hookeri (Cl.) Van	Sapotaceae	6.4	–	–
Zanthoxylum armatum DC.	Rutaceae	3.6	–	–
Shrub species				
Achyranthes aspera L.	Amaranthaceae	–	–	5.1
Agapetes variegata (Roxb.) G. Don.	Ericaceae	19.4	–	3.5
Alchornea tilifolia (Benth.) Muell.-Arg.	Euphorbiaceae	19.7	9.4	–
Antidesma diandrum (Roxb.) Roth.	Euphorbiaceae	–	–	3.1
Aralia chinensis L.	Araliaceae	–	3.3	–

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Ardisia crispa (Thunb.) DC.	Myrsinaceae	–	2.6	15.5
Ardisia floribunda Wall.	Myrsinaceae	–	12.3	–
Baliospermum calycinum Muell.-Arg.	Euphorbiaceae	32.1	5.5	–
Berberis wallichiana DC.	Berberidaceae	–	–	4.2
Boehmeria platyphylla D. Don	Urticaceae	–	–	2.3
Boehmeria sidaefolia Wedd.	Urticaceae	–	2.4	–
Buddleja asiatica Lour.	Loganiaceae	–	–	5.1
Calliandra griffithii Benth.	Mimosaceae	–	8.3	–
Callicarpa rubella Lindl.	Verbenaceae	–	2.6	–
Camellia caduca Brandis	Theaceae	64.1	16.4	–
Casearia vareca Roxb.	Flacourtiaceae	–	–	4.8
Chloranthes glaber (Thunb.) Makino	Chloranthaceae	4.4	2.4	–
Cinnamomum pauciflorum Nees	Lauraceae	–	3.0	–
Citrus medica L	Rutaceae	–	–	10.1
Clerodendrum colebrookianum Walp.	Verbenaceae	–	–	10.5
Clerodendrum serratum (L.) Spreng.	Verbenaceae	–	–	19.3
Clerodendrum viscosum Vent.	Verbenaceae	12.1	–	3.8
Clerodendrum wallichii Merr.	Verbenaceae	–	12.5	8.7
Coffea khasiana Hook.f.	Rubiaceae	3.3	–	–
Daphne involucrata Wall.	Thymelaeaceae	7.7	6.3	–
Debregeasia longifolia Wedd.	Urticaceae	–	–	5.3
Desmodium heterocarpon (L.) DC.	Fabaceae	–	–	1.9
Desmodium pulchellum (D.) Benth.	Fabaceae	–	8.8	–
Desmos chinensis Lour.	Annonaceae	–	4.8	–
Eriobotrya angustissima Hk.f.	Rosaceae	–	4.0	–
Eriosema himalaicum Ohashi	Fabaceae	4.4	2.4	1.8
Erythroxylum kunthianum Wall. ex Kurz	Erythroxylaceae	25.0	11.9	28.1
Eupatorium odoratum L.	Asteraceae	–	–	7.7
Eurya japonica Thunb.	Theaceae	97.5	33.1	–
Ficus gasperriniana Miq.	Moraceae	–	6.4	–
Ficus hispida L.	Moraceae	–	–	3.4
Ficus sarmentosa J.E. Smith	Moraceae	–	–	3.1
Flemingia macrophylla (Willd.) Prain	Fabaceae	4.4	–	7.3
Gardenia campanulata Roxb.	Rubiaceae	–	3.8	–
Glochidion lanceolarium (Roxb.) Voigt	Euphorbiaceae	–	5.9	–
Glycosmis longifolia (Hook.f.) Tanaka	Rutaceae	–	–	3.0
Goldfussia glabrata (Nees) Balak.	Acanthaceae	–	2.4	–
Goniothalamus sesquipedalis (Wall.) Hk. f. & Th.	Annonaceae	5.3	–	–
Hibiscus surattensis L.	Malvaceae	–	2.7	4.3

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Hiptage benghalensis (L.) Kurz	Malpighiaceae	27.9	9.9	11.0
Ixora roxburghii Balakr.	Rubiaceae	–	–	2.5
Ixora subsessilis G. Don.	Rubiaceae	6.0	–	–
Lantana camara L.	Verbenaceae	–	–	42.5
Leea crispa Linn.	Leeaceae	–	–	13.5
Leptodermis griffithii Hook.f.	Rubiaceae	–	–	2.2
Leucosceptrum canum Smith	Lamiaceae	–	–	1.9
Loranthus scurrula L.	Loranthaceae	11.8	–	–
Maesa tetrandra (Roxb.) DC.	Myrsinaceae	7.0	–	28.9
Mallotus leucocarpus (Kurz) Airy-Shaw	Euphorbiaceae	–	–	2.3
Melastoma malabathricum L.	Melastomataceae	–	115.5	–
Morus australis Poir.	Moraceae	–	3.5	–
Mussaenda roxburghii Hook. F.	Rubiaceae	26.3	21.7	6.6
Olax acuminata Benth.	Olacaceae	–	10.0	8.1
Orthosiphon incurvus Benth.	Lamiaceae	–	2.4	–
Osbeckia stellata Ker.-Gawl.	Melastomataceae	10.3	2.9	2.0
Oxyspora paniculata DC.	Melastomataceae	–	6.4	–
Phyllanthus parvifolius Buch.-Ham.	Euphorbiaceae	–	2.4	18.1
Phyllanthus roeperianus Muell.-Arg.	Euphorbiaceae	16.9	–	34.3
Pilea umbrosa Wedd.	Urticaceae	–	–	1.8
Pittosporum podocarpum Gagnepain	Pittosporaceae	–	13.9	–
Polyalthia cerasoides (Roxb.) Bedd.	Annonaceae	5.7	7.9	–
Psychoria monticola Kurz	Rubiaceae	–	–	6.9
Pteracanthus griffithianus (Nees)Bremek.	Acanthaceae	–	–	2.0
Rhamnus napalensis (Wall.) Laws.	Rhamnaceae	–	–	7.2
Rinorea bengalensis (Wall.) O. Ktze.	Violaceae	–	–	2.0
Rubus ellipticus Smith	Rosaceae	–	6.9	–
Sambucus javanica Bl.	Caprifoliaceae	–	–	4.1
Sarcochlamys pulcherrima (Roxb.) Gaud.	Urticaceae	–	–	2.7
Saurauia punduana Wall.	Saurauiaceae	–	–	5.7
Sauropus androgynus (L.) Merr.	Euphorbiaceae	4.4	–	15.9
Solanum aculeatissimum Jacq.	Solanaceae	–	–	3.7
Tabernaemontana divaricata (L.) R. Br.	Apocynaceae	–	–	2.9
Urena lobata L.	Malvaceae	–	5.1	1.8
Vaccinium griffithianum Wt.	Vacciniaceae	3.0	–	–
Villebrunea integrifolia Gaud.	Urticaceae	–	–	7.0
Herbaceous species				
Abutilon indicum (L.) Sweet	Malvaceae	–	–	1.6
Achyranthes bidentata Bl.	Amaranthaceae	–	–	0.8
Ageratum conyzoides L.	Asteraceae	–	0.9	–

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Alocasia fornicata (Roxb.) Schott	Araceae	–	–	1.5
Alpinia allughas (Retz.) Rosc.	Zingiberaceae	–	1.0	0.8
Alternanthera sessilis (L.) R. Br.	Amaranthaceae	0.8	–	–
Amomum aromaticum Roxb.	Zingiberaceae	16.2	0.9	3.2
Anisomeles indica (L.) O. Ktze.	Lamiaceae	–	–	0.8
Argostemma khasianum Clarke	Rubiaceae	–	1.3	–
Artemisia parviflora Roxb.	Asteraceae	–	–	6.2
Aster trinervius D. Don	Asteraceae	–	1.5	–
Begonia ovalifolia DC.	Begoniaceae	–	1.0	–
Begonia palmata D.Don	Begoniaceae	15.5	8.2	–
Begonia roxburghii (Miq.) DC.	Begoniaceae	26.7	13.9	–
Bidens pilosa L.	Asteraceae	–	–	10.1
Blumea alata (D. Don) DC.	Asteraceae	–	–	6.6
Bulbophyllum griffithii (Lindl.) Reichb. f.	Orchidaceae	–	–	0.8
Calamintha umbrosa (Bieb.) Benth.	Lamiaceae	12.2	–	–
Campanula fulgens Wall.	Campanulaceae	–	–	1.1
Canna coccinea Mill.	Cannaceae	–	2.8	1.5
Canscora andrographioides Clarke	Gentianaceae	–	–	0.8
Centella asiatica (L.) Urban	Apiaceae	–	–	60.2
Centranthera cochinchinensis (Lour.) Merr.	Scrophulariaceae	–	1.3	–
Chlorophytum khasianum Hook.f.	Liliaceae	–	–	2.7
Codonacanthus pauciflorus (Nees) Nees in DC.	Acanthaceae	–	–	1.7
Colocasia affinis Schott	Araceae	–	4.9	0.8
Commelina appendiculata Clarke	Commelinaceae	–	1.6	3.3
Crinum amoenum Roxb.	Amaryllidaceae	4.4	–	–
Curculigo orchioides Gaertn.	Hypoxidaceae	2.7	–	–
Curcuma speciosus (Koenig) Smith	Zingiberaceae	–	1.0	–
Cyanotis vaga (Lour.) J.A. & J.H. Schult.	Commelinaceae	–	3.1	–
Cymbopogon khasianus (Duthie) Bor	Poaceae	–	1.6	–
Cyperus cyperoides (L.) O. Ktze.	Cyperaceae	–	6.7	–
Cyperus halpan L.	Cyperaceae	–	7.2	–
Cyperus kyllinga Endl.	Cyperaceae	–	5.4	–
Cyperus pilosus Vahl	Cyperaceae	–	3.0	–
Dianella ensata (Thunb.) R.J. Henderson	Liliaceae	–	–	1.5
Dichrocephala bicolor (Roth) Schltdl.	Asteraceae	–	–	0.9
Digitaris longiflora (Retz.) Pers.	Poaceae	–	3.3	–
Disporum calcaratum D. Don	Liliaceae	–	1.0	–
Drymaria cordata (L.) Roem. & Schult.	Caryophyllaceae	–	1.5	–

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Duchesnea indica (Andr.) Focke	Rosaceae	–	–	2.8
Dysophylla linearis Benth.	Lamiaceae	–	0.9	–
Echinochloa crus-galli (L.) P. Beauv.	Poaceae	1.7	2.1	–
Eleusine indica (L.) Gaertn.	Poaceae	–	2.5	–
Elsholtzia stachyodia (Link) Raiz. & Sax	Lamiaceae	5.7	6.6	2.9
Erianthus longisetosus Anderss.	Poaceae	–	1.8	0.9
Eupatorium nodiflorum DC.	Asteraceae	–	–	4.8
Forrestia mollissima (Bl.) Kds.	Commelinaceae	–	–	1.8
Galingsoga parviflora Cav.	Asteraceae	–	–	2.5
Gentiana quadrifaria Bl.	Gentianaceae	–	1.5	1.9
Girardinia palmata (Forsk.) Gaud.	Urticaceae	–	1.3	–
Globba racemosa Smith.	Zingiberaceae	–	–	0.8
Gomphostemma ovatum Benth.	Lamiaceae	1.4	–	–
Gynura crepidioides Benth.	Asteraceae	–	–	3.4
Habenaria khasiana Hook. f.	Orchidaceae	1.4	–	–
Hedychium dekianum Rao & Verma	Zingiberaceae	8.5	7.3	1.8
Hedyotis ovalifolia Cav.	Rubiaceae	7.1	4.2	–
Hornstedtia linguiformis (Schult.) K. Schum.	Zingiberaceae	–	–	0.9
Houttuynia cordata Thunb.	Saururaceae	4.7	2.7	15.8
Hydrocotyle javanica Thunb.	Apiaceae	–	–	2.0
Impatiens porrecta Hook.f & Th.	Balsaminaceae	–	2.1	–
Impatiens trilobata Coleb.	Balsaminaceae	–	–	6.6
Justicia vasculosa (Nees) T. And.	Acanthaceae	–	1.0	–
Lobelia angulata Forst.	Campanulaceae	1.7	6.7	0.8
Molineria capitulata (Lour.) Herb.	Hypoxidaceae	–	–	1.9
Ophiorrhiza pauciflora Hook.f	Rubiaceae	2.7	4.9	–
Osbeckia capitata Naudin	Melastomataceae	–	2.5	–
Oxalis corniculata L.	Oxalidaceae	–	2.5	1.4
Panicum humidorum Hook.f.	Poaceae	1.4	11.5	–
Paris polyphylla Smith	Liliaceae	1.7		–
Paspalum compactum Roth	Poaceae	16.2	3.0	0.9
Paspalum conjugatum Berg.	Poaceae	–	9.3	–
Phrynium pubinerve Bl.	Maranthaceae	–	–	0.8
Phyllanthus urinaria L.	Euphorbiaceae	10.5	4.8	6.6
Plantago erosa Wall.	Plantaginaceae	4.9	–	–
Pogonatherum rufo-barbatum Griff.	Poaceae	–	2.7	–
Pogostemon auricularius (L.) Hassk.	Lamiaceae	2.7	–	–
Pogostemon strigosus Benth.	Lamiaceae	–	14.8	1.5

Appendix 1. (Continued)

Plant species	Family	UM	CM	LM
Polygala glomerata Lour.	Polygalaceae	–	3.1	1.6
Polygonum dibotrys D. Don.	Polygonaceae	–	–	1.6
Polygonum tenellum Bl.	Polygonaceae	–	5.1	–
Potentilla fulgens Wall.	Rosaceae	–	–	2.0
Pouzolzia hirta (Bl.) Hassk.	Urticaceae	–	9.3	2.0
Rhaphidophora grandis Schott	Araceae	–	1.0	–
Saccharum arundinaceum Retz.	Poaceae	–	0.9	1.6
Scirpus mucronatus L.	Cyperaceae	2.0	–	0.8
Scutellaria discolor Colebr.	Lamiaceae	54.8	1.9	–
Setaria palmifolia (Koen.) Stapf	Poaceae	–	1.0	–
Sida rhombifolia L.	Malvaceae	–	–	2.4
Solanum khasianum Clarke	Solanaceae	–	2.2	2.1
Solanum nigrum Linn.	Solanaceae	–	–	2.5
Sonchus oleraceus Linn.	Asteraceae	–	–	3.9
Spilanthes paniculata DC.	Asteraceae	–	1.8	–
Teucrium quadrifarium Buch.-Ham.	Lamiaceae	–	1.0	–
Thysanolaena maxima (Roxb.) O. Ktze.	Poaceae	–	–	0.8
Vernonia cinerea (L.) Less.	Asteraceae	–	1.3	1.8
Viola palmaris Ging.	Violaceae	–	0.9	–

(– indicates absence of the species)

Chapter 5

Impact of Mining on Soil

Conversion of forests for developmental activities has received increasing attention in recent years because of its impact on soil productivity and contribution to global warming (Asio et al. 1998). In large parts of the tropical belts, currently under tropical forest, soils are generally poor and the low nutrient availability seriously hampers land use, other than extensive forestry (Brouwer and Riezebos 1998). The relationship between soil conditions and biodiversity of the natural vegetation is more complex. This is linked with the various aspects of biodiversity (Kauffman et al. 1998).

Forest depletion due to mining is believed to be the major cause of widespread occurrence of degraded lands in Meghalaya. Soil degraded by mining activities become impoverished because mining environment alters the natural conditions of soils and provides a very rigorous condition for plant growth. However, no work has been conducted on the impact of mining on soil characteristics. This research is, therefore, conducted to study the impact of mining on soil physicochemical properties in the mining areas of Jaintia Hills of Meghalaya.

Methodology

Soil samples were collected from 0-10 cm and 10-20cm of the mining and un-mined areas by using a soil corer, for four seasons over a period of two years. Samples were air dried (except those for pH in $CaCl_2$), weighed (after separating the stone fragments), crushed to pass through 2mm diameter sieve and then stored in covered glass bottles. Organic carbon (OC) was determined by Walkley-Black method, and then multiplied by 1.72 to obtain percent of OC; Nitrogen content (N) was determined by Kjeldahl method; available Phosphorus (P) by using Bray 2 solution (for extraction); and the method of Murphy and Riley (1962) was followed for color development. Available K was analyzed by flame photometry, and soil pH (0.01 M $CaCl_2$) was determined potentiometrically on fresh soil samples using a ratio of 1:2.5 (Anderson and Ingram 1993).

Descriptive statistics for evaluating soil physicochemical properties were used for each of the soil samples taken from unmined, coal mining and limestone mining sites. Replicates were averaged to determine means utilized for data analysis with ANOVA comparative statistics. The significance level was $P<0.05$ in all cases. Analyses were carried out using SYSTAT package (Wilkinson 1990).

Results and Discussion

Selected key analytical characteristics, relevant for land use analysis and ecological research are presented in this section. For physicochemical properties of soil in unmined, coal mining and limestone mining sites, the mean value was considered to show trends and differences between the study sites. Multivariate analysis at the $P<0.05$ level showed that soil characters significantly differ between sites, years and seasons and are given below.

Multivariate Analysis

Effect	Wilks Lambda	Ho Df	Error Df	F	Probability
Site	0.000	24	314	834.287	0.000
Years	0.008	12	157	1672.338	0.000
Seasons	0.000	36	465	179.995	0.000
Site*Years	0.229	24	314	14.247	0.000
Site*Seasons	0.000	72	860	42.130	0.000
Years*Seasons	1.000	36	465	0.000	-
Site*Years*Seasons	1.000	72	860	0.000	-

Temperature

Soil temperature is one of the basic physical factors that alter the soil parameters. From the present study, it was observed that the minimum and maximum temperature in unmined, coal and limestone mining sites ranged from 19.96-22.04, 18.70-23.5 and 15.00-23.50^{0}C respectively. The mean minimum temperature was recorded during rainy season in coal mining site (Figure 2.1). Analysis of variance shows that at $P<0.05$ level, temperature significantly differs between sites, years and seasons (Table 2.1). The loss of soil nutrients in mining area usually occurs by mineralization and leaching of heavy metals, changes in soil moisture and temperature regimes. Studies conducted by Shrestha and Lal (2006) in ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil, reported that increase in soil temperature, increases the rate of mineralization of the SOC pool.

Figure 2.1. Soil temperature in the unmined and mining areas of Jaintia Hills

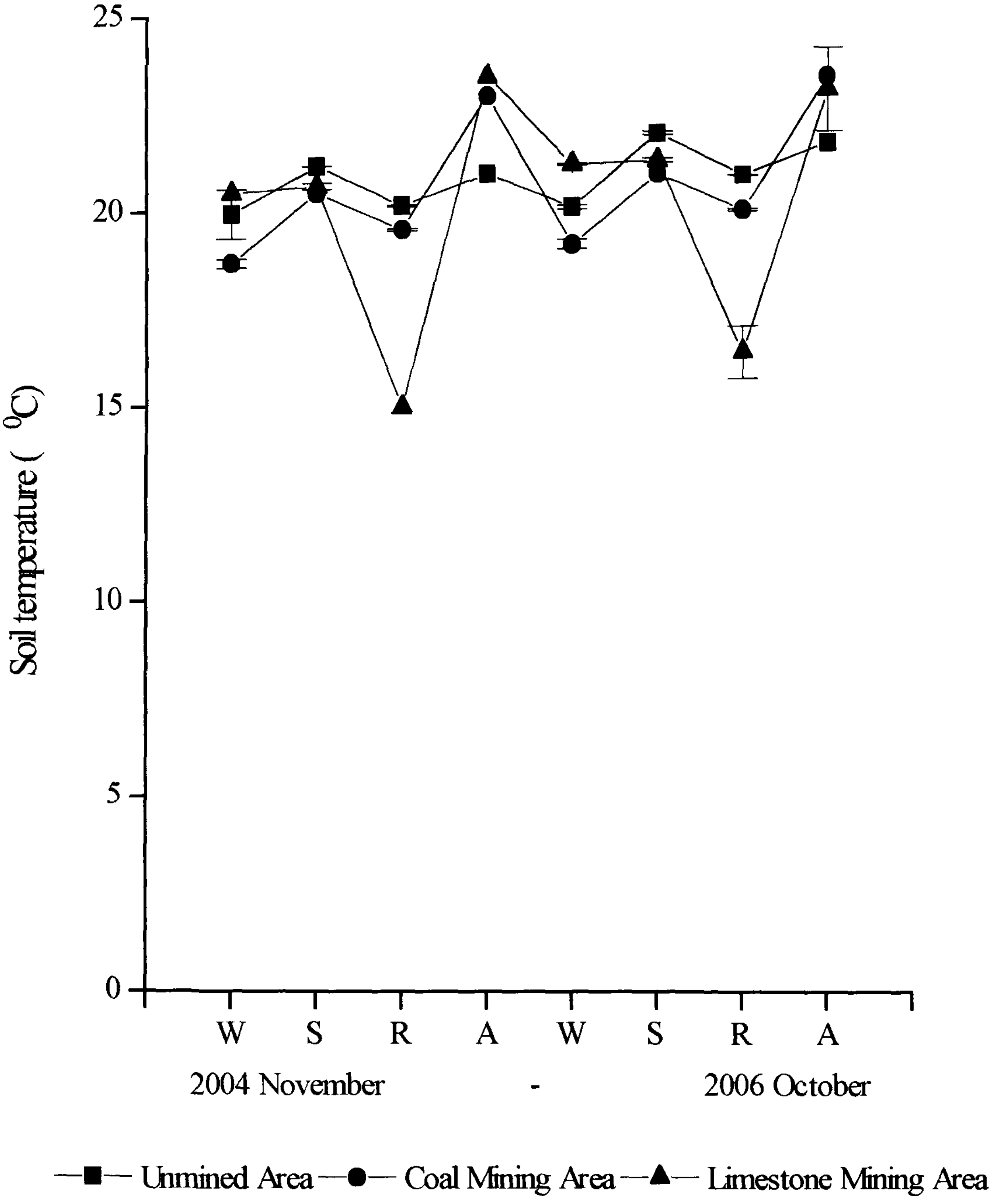


Table 2.1. Results of ANOVA of changes in available soil temperature in different study sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil Temperature	Model	837.683	23	36.421	2274.619	0.000
	Error	2.690	168	0.016		
	Total	840.373	191			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil Temperature	Site	11.340	2	5.670	354.112	0.000
	Years	19.253	1	19.253	1202.439	0.000
	Seasons	474.856	3	158.285	9885.475	0.000
	Site*Years	0.507	2	0.253	15.822	0.000
	Site*Seasons	331.727	6	55.288	3452.917	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

Moisture Content

During the monitoring period, the soil moisture content showed a definite trend with the unmined site recording the highest moisture level (31.37%) in the topsoil and subsurface layer (29%) compared with the coal mining area (Figure 2.2). However, the highest proportion of moisture content was recorded in limestone mining area. It is due to the clayey nature of the soil in limestone mining area. The soil moisture content significantly differs between site and seasons but it did not vary significantly between the sites, years and seasons (Table 2.2). Baig (1992) reported severe moisture deficiency in the coalmine spoils of the rocky mountains of Alberta during revegetation. The study conducted by Das Gupta et al. (2002) who recorded low moisture content in the coal mining areas considered moisture an important factor limiting plant growth. The finding of the present study is, thus, in agreement with the findings of the above works.

Figure 2.2. Soil Moisture content in the unmined and mining sites of Jaintia Hills

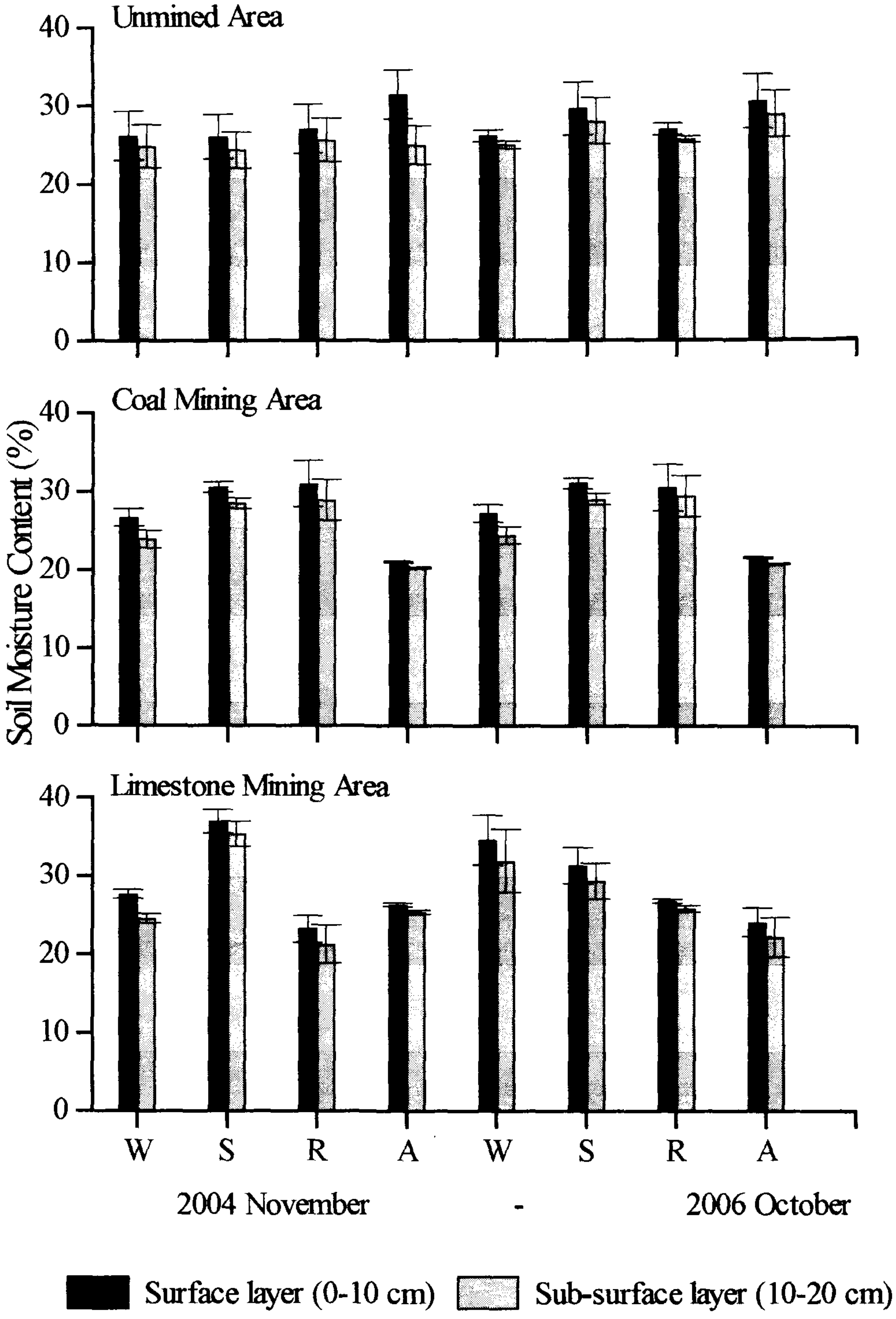


Table 2.2. Results of ANOVA of changes in available soil moisture content in different study sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Moisture Content	Model	3785.697	23	164.596	21.867	0.000
	Error	1264.540	168	7.527		
	Total	5050.237	191			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Moisture Content	Site	74.263	2	37.131	4.933	0.008
	Years	19.253	1	19.253	2.558	0.112
	Seasons	2181.167	3	727.056	96.593	0.000
	Site*Years	0.507	2	0.253	0.034	0.967
	Site*Seasons	1510.507	6	251.751	33.446	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

Soil pH

The behavior of pH of soil under the different study sites is shown in figure 3. As can be seen, there is a tendency for pH to be slightly high in limestone mining area and low in coal mining area than in the unmined area. The soil pH in the unmined area ranged from 4.8 – 6.0 and shows acidic in nature. The soil became highly acidic in coal mining areas and was recorded to range between 4.05 - 4.53 in the topsoil. However, it was found to be alkaline in limestone mining area and ranged from 6.8 - 8.18 (Figure 2.3). The soil pH was significantly different at the $P<0.05$ level in all the sites across all the seasons (Table 2.3). During the rainy season, pH was significantly lower than in the other seasons. It may be due to the heavy leaching of soils during rainy seasons.

Figure 2.3. Soil pH in the unmined and mining sites of Jaintia Hills

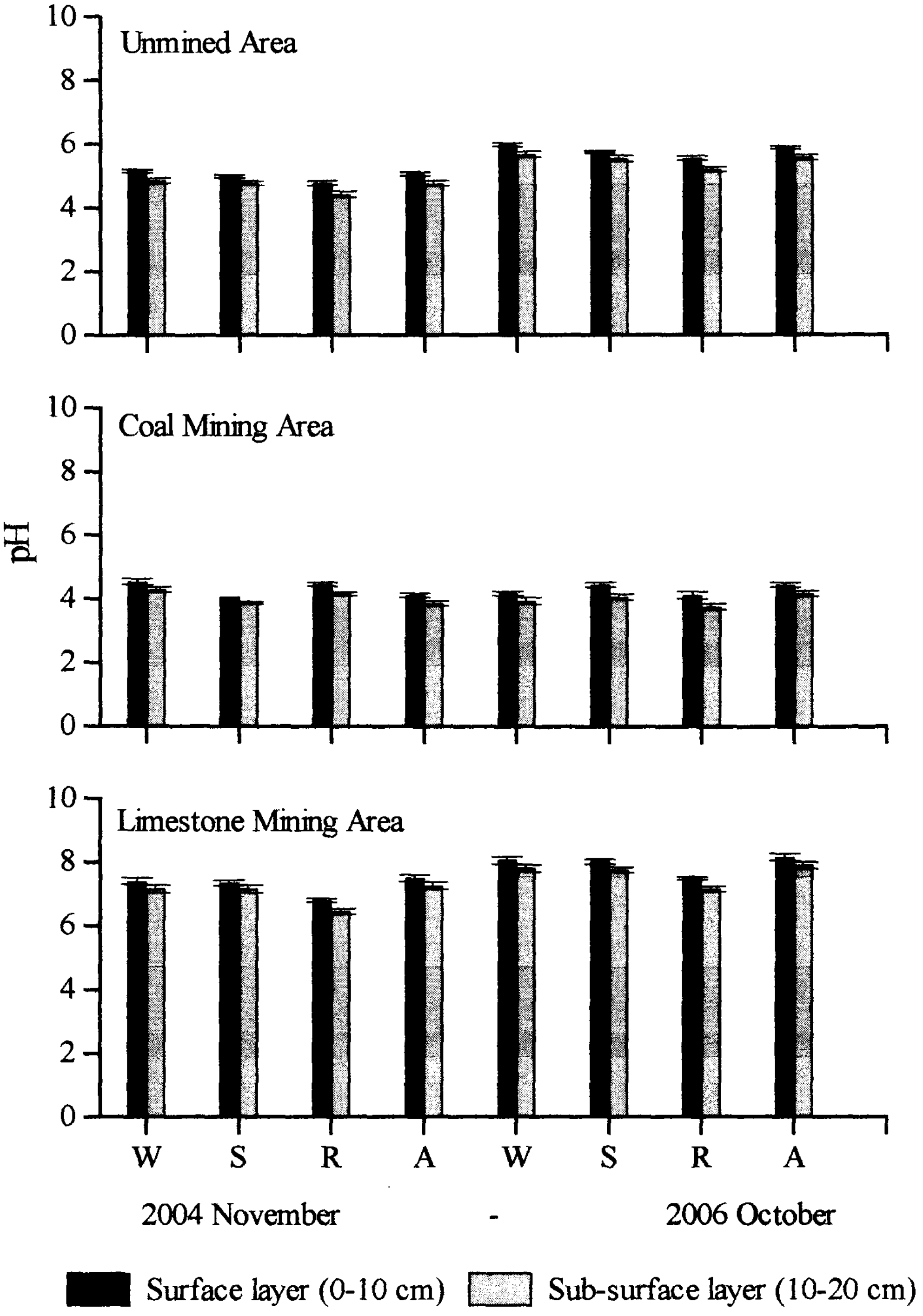


Table 2.3. Results of ANOVA of changes in available soil pH different study sites of Jaintia Hills

Overall tests of univariate models						
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil pH	Model	279.797	23	12.165	240.156	0.000
	Error	8.510	168	0.051		
	Total	288.307	191			

Tests of univariate effects						
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil pH	Site	251.679	2	125.840	2484.252	0.000
	Years	19.253	1	19.253	380.088	0.000
	Seasons	6.618	3	2.206	43.548	0.000
	Site*Years	0.507	2	0.253	5.001	0.008
	Site*Seasons	1.740	6	0.290	5.725	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

The soil of the area, in general, was acidic in reaction. The site affected by coal mining were more acidic than the unmined and limestone mining sites. The increase in pH due to mining has been attributed to the oxidation of iron pyrites (Banks et al. 1997; Kirby and Brady 1998; Braungardt et al. 2003). Decline and increase of pH in coal mining and limestone mining areas is one of the serious problems associated with coal mining activity. Drastic pH changes can adversely affect plant growth in various ways including the availability of a large number of essential nutrients in the soil (Coyne et al. 1998; Mayes et al. 2005).

Organic Carbon (OC)

Terrestrial ecosystems play a major role in moderating the global carbon (C) cycle. The human perturbations of the C cycle directly affect ecosystem function. The percentage of soil organic carbon drastically reduced due to mining activity. The percentage of organic carbon in the coal and limestone mining areas ranged from 1.47 to 1.83 and 1.718 to 1.783 in topsoil and 1.19 to 1.60 and 1.50 to 1.63 in sub-surface layer respectively, while in unmined area it ranged between 2.5 to 2.6 in topsoil and 2.3 to 2.5 in sub-surface layer (Figure 2.4). The soil OC percentage decreased significantly with increasing depths. The soil OC content varied significantly ($P<0.05$) among different sites and seasons studied (Table 2.4).

Table 2.4. Results of ANOVA of changes in available soil organic carbon content in different study sites of Jaintia Hills

Overall tests of univariate models

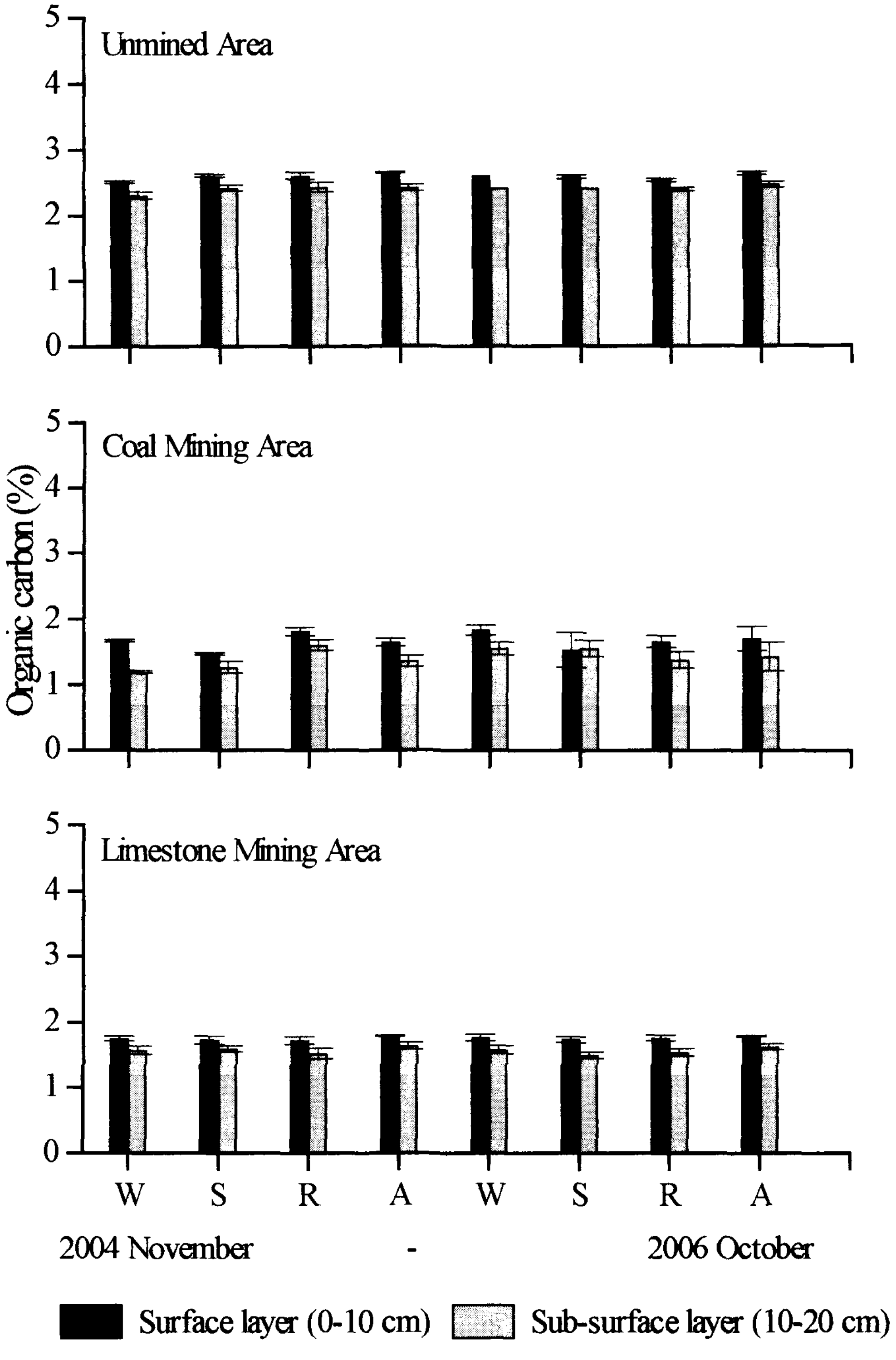
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil OC	Model	26.433	23	1.149	47.944	0.000
	Error	4.027	168	0.024		
	Total	30.461	191			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil OC	Site	5.606	2	2.803	116.928	0.000
	Years	19.253	1	19.253	803.173	0.000
	Seasons	0.270	3	0.090	3.757	0.012
	Site*Years	0.507	2	0.253	10.568	0.000
	Site*Seasons	0.797	6	0.133	5.544	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

Smith et al. (1994) reported that mining activities can accentuate CO_2 emissions from mineralization of soil organic matter (SOM) by soil disturbances and fluxes of C from fell biomass decomposition (Indorante et al. 1981; Coyne et al. 1998). The loss of carbon pool in disturbed soil usually occurs by mineralization, erosion and leaching, which also changes the soil moisture, temperature regimes and the reduction in amount of biomass returned to the soil (Izaurralde et al. 2000). Similar results have been reported by Shrestha and Lal (2006).

Figure 2.4. Soil OC content in the unmined and mining sites of Jaintia Hills



Nitrogen (N)

Figure 2.5 and Table 2.5 show that the nitrogen content generally decrease in the coal mining and limestone mining area. ANOVA shows the significant reduction ($P<0.05$) in soil nitrogen content due to mining activity among different sites and seasons. However, it did not varied significantly between site years and seasons. In the unmined site, it ranged between 276 - 293 (Kg/ha^{-1}) in the topsoil and 247 - 270 (Kg/ha^{-1}) in sub-surface soil studied, while in the coal and limestone mining sites it was reduced to 247 – 266 and 271 – 280 (Kg/ha^{-1}) in topsoil and it varied from 177 – 237 and 245 – 255 (Kg/ha^{-1}) in sub-surface soil layer respectively. The reduction of nitrogen content was found to be significantly decreasing with increasing depth.

The mining activities had significant impact on soil nitrogen content. Remon et al. (2005) recorded low nitrogen content in a former metallurgical landfill, France. Low nitrogen content in the mining site could be attributed to the high level of mineralization of organic materials.

Table 2.5. Results of ANOVA of changes in available soil N content in different study sites of Jaintia Hills

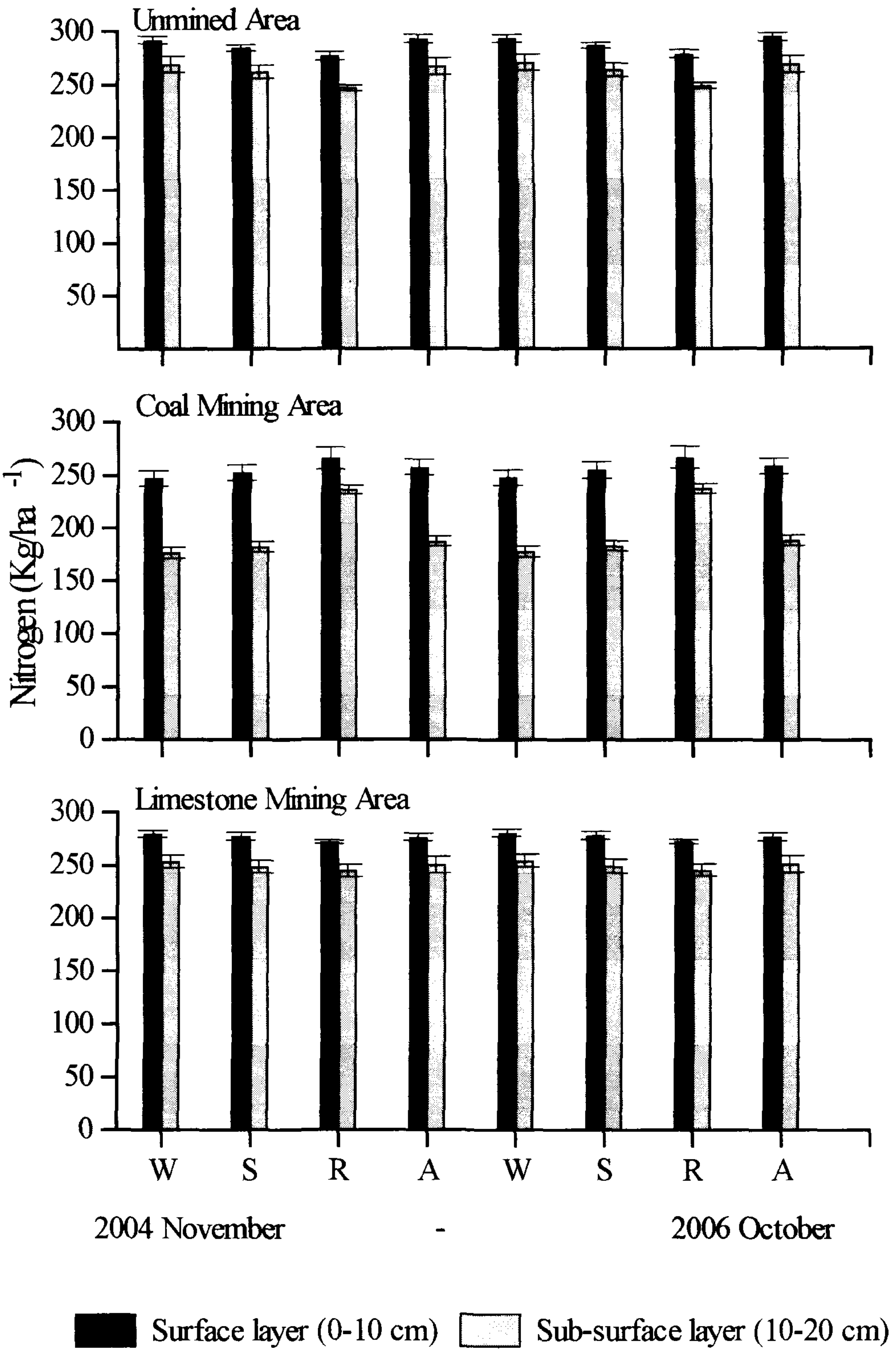
Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil N	Model	101038.917	23	4392.996	7.160	0.000
	Error	103073.000	168	613.530		
	Total	204111.917	191			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil N	Site	82302.407	2	41151.203	67.073	0.000
	Years	19.253	1	19.253	0.031	0.860
	Seasons	899.417	3	299.806	0.489	0.691
	Site*Years	0.507	2	0.253	0.000	1.000
	Site*Seasons	17817.333	6	2969.556	4.840	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

Figure 2.5. Soil nitrogen content in the unmined and mining areas of Meghalaya



Available P

The pattern of nutrient limitation is indicated by the types of land use and the available nutrient content in the soil. The results revealed that mining activities alters the soil P content (Figure 2.6). The availability of P ranged between 10.2 – 12.3, 7.0 – 9.0 and 9.0 – 11.0, 0.25 – 0.58 in top, sub-surface soil layer in coal and limestone mining areas respectively. Thus, the available P is higher in coal mining areas. However it was low in unmined area, and ranged from 8.0 – 9.0, 7.23 – 7.25 in the topsoil and sub-surface soil layers, respectively. ANOVA shows the significant variation between site and seasons ($P<0.05$), but it did not vary much between years and seasons (Table 2.6).

As regards to the available P, results revealed that mining activities tend to increase their amount in the soil. The high concentration of P content in mining sites could be related to leaching of minerals due to mining activities.

Table 2.6. Results of ANOVA of changes in available soil P content in different study sites of Jaintia Hills

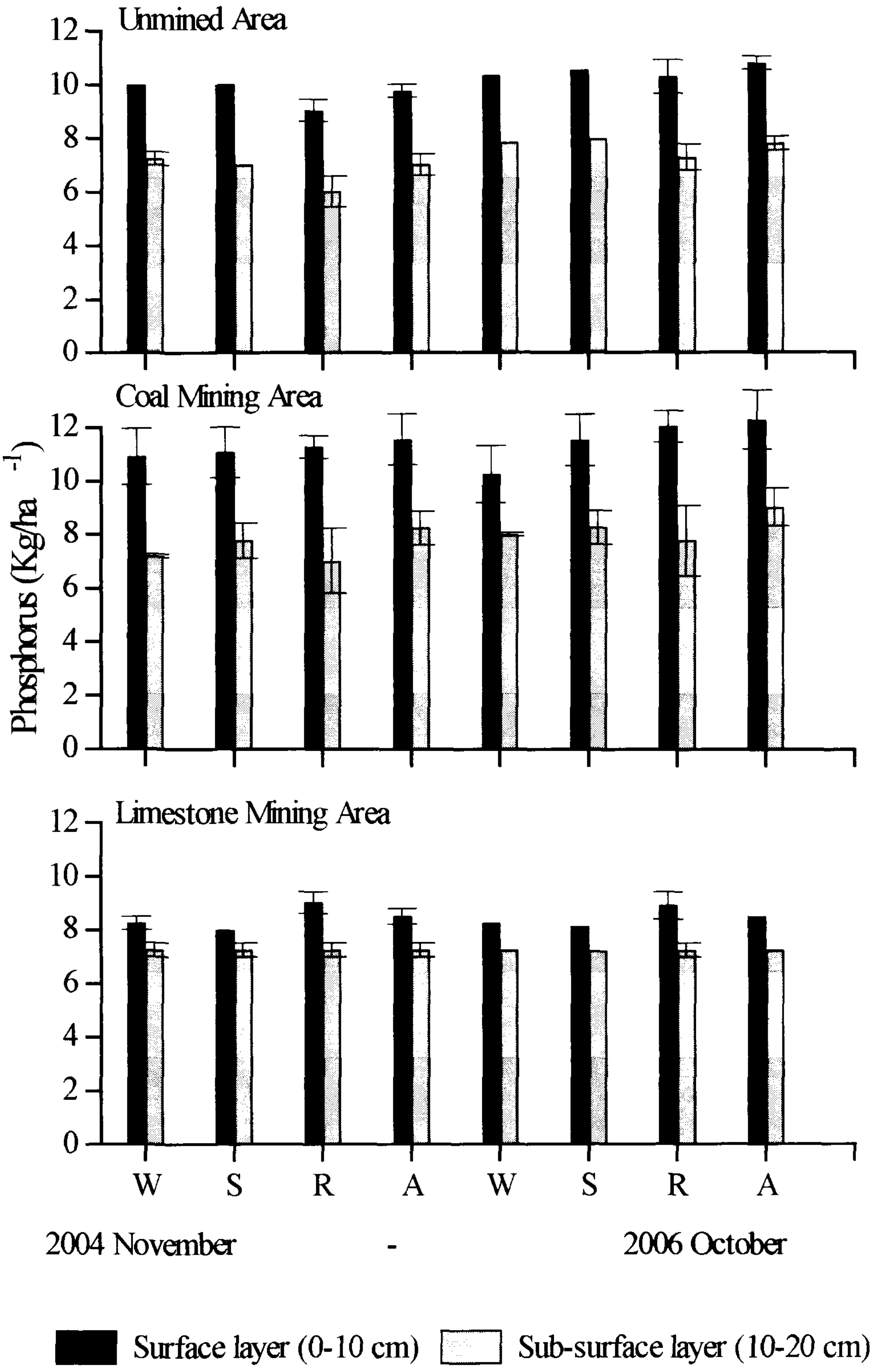
Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil P	Model	529.428	23	23.019	7.764	0.000
	Error	498.058	168	2.965		
	Total	1027.485	191			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil P	Site	9.148	2	4.574	1.543	0.217
	Years	19.253	1	19.253	6.494	0.012
	Seasons	150.185	3	50.062	16.886	0.000
	Site*Years	0.507	2	0.253	0.085	0.918
	Site*Seasons	350.335	6	58.389	19.695	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

Figure 2.6. Soil phosphorus content in the unmined and mining sites of Jaintia Hills



Available K

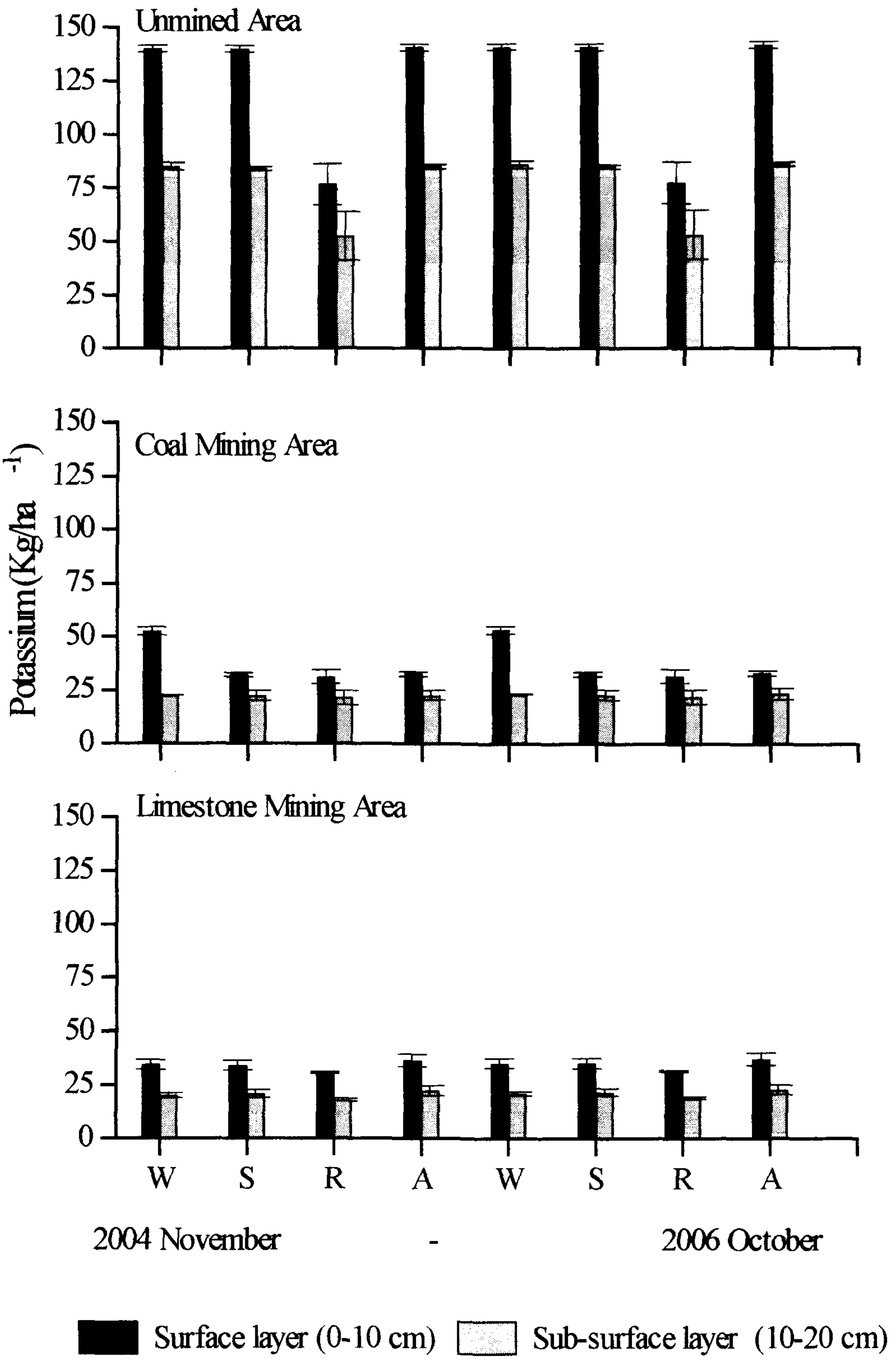
The available K content was highest in the soil under unmined area followed by the soil under limestone mining area. The soil under coal mining area gave the lowest available K (Figure 2.7). ANOVA shows the significant decrease ($P<0.05$) of soil K due to mining activity between sites and seasons (Table 2.7). Mean values of available K from the surface samples revealed that the significant variability among sites could have been caused by the mining activity.

Table 2.7. Results of ANOVA of changes in available soil K content in different study sites of Jaintia Hills

		Overall tests of univariate models				
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil K	Model	249022.229	23	10827.053	33.349	0.000
	Error	54542.170	168	324.656		
	Total	303564.399	191			
		Tests of univariate effects				
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Soil K	Site	220088.120	2	110044.060	338.956	0.000
	Years	19.253	1	19.253	0.059	0.808
	Seasons	12864.587	3	4288.196	13.208	0.000
	Site*Years	0.507	2	0.253	0.001	0.999
	Site*Seasons	16049.761	6	2674.960	8.239	0.000
	Years*Seasons	0.000	3	0.000	0.000	1.000
	Site*Years*Seasons	0.000	6	0.000	0.000	1.000

The litter decomposition and animal residues could have contributed to high available K under unmined area. Generally, the lower available K in the coal and limestone mining sites can be attributed to losses by leaching and erosion. Asio et al. (1998) observed similar trend and concluded that the availability of nutrients in soil is closely related to

Figure 2.7. Potassium content in the unmined and mining sites of Jaintia Hills



the pattern of land use and disturbance. Raizada et al. (2004) reported that soil erosion and deforestation increase loss of nutrients from the ecosystem leading to reduction in soil fertility, carbon fixation and organic matter accumulation. Thus, the enhancement of soil nutrients is essential to restore the mining sites for developing multi-stratal canopy on the mine spoil. This also requires suitable soil and water conservation measures along with vegetation, which will allow for organic matter enrichment, speed up nutrient cycling and reduce soil erosion.

Chapter 6

Impact of Mining on Water Quality

The water quality functioning of river systems is important in relation to ecological status and environmental management (Neal et al. 2005), and plays important and unique roles for society through provisioning, supporting and enriching services (Postel and Carpenter 1997; Covich et al. 2004). However, the number and magnitude of anthropogenic stressors that threaten these services is growing rapidly (Giller et al. 2004). These arise from the myriad of human activities that include engineering, pollution and forced climate change and overexploitation of natural resources (Postel and Carpenter 1997; Malmqvist and Rundle 2002). These stressors are both internal, such as direct pollution and geomorphic engineering of the river channel, and external, for example through land-use change in the catchment area (Giller 2005). Many areas worldwide are contaminated to a greater extent by metals originating from mining and smelting of metal ores (Groenendijk et al. 2002).

Acid mine drainage evolved from reduced sulfur materials that have been oxidized on exposure to water and oxygen, a process often brought about by mining activities. The pyrite oxidation reactions produce sulfuric acid and ferric hydroxides and mobilize other trace metals depending on the surrounding mineralogy. Those toxic acids and metals flow to surface waters, where the acid is eventually neutralized, causing metals to precipitate and coat streambeds with metal oxides, impairing habitat and adversely affecting water quality (Schmidt et al. 2002; Blodau 2006). The biotic effects associated with AMD which impact surface waters include acute impairment of aquatic organisms as a result of low pH and elevated levels of dissolved heavy metals (Kullberg 1992).

The impact of limestone extraction on the surface water can encompass hydrological issues, hydrochemical changes and problems associated with increased sediment loadings, upon entering receiving water bodies. However, published accounts of the nature of such impacts has to-date been largely restricted to qualitative accounts and the conjectural assessments of possible interactions between quarrying activity and the surrounding hydrological environment (Mayes et al. 2005).

Mine water pollution is a major cause of surface and groundwater pollution in mining areas throughout world. It is a potential barrier to achieving good status of water bodies, which is a requirement of the Water Framework Directive. In the mining areas, a concerted effort has been made over the last decade or so to address the scientific and practical challenges relating to the remediation of mine water pollution (Gandy et al. 2007).

Jaintia Hills of Meghalaya has a large number of rivers and streams that drain the undulating landscape of the area. These water bodies serve as important sources for drinking water, irrigation and support a rich array of floral and faunal diversity of the locale. Unfortunately, rampant mining activities has adversely affected the quality of water of most aquatic ecosystems. Drainage originating from mines, leaching of heavy metals and organic enrichment by various anthropogenic activities are the main sources of water pollution which has serious implications on aquatic life, agricultural activities and availability of potable and irrigation water in the area. In view of this fact, the present study was aimed to determine the quality of water in mining areas of Jaintia Hills of Meghalaya to see, how the discharge of mine drainage affect the water quality. For answering the above question, I studied the water quality of the surface water bodies of the area.

Methodology

Water samples were collected from the mining and unmined areas of Jaintia Hills on seasonal basis (Winter, Spring, Rainy and Autumn) over a period of two years from four locations (upstream to downstream namely station - 1 to station - 4) by using Van Dorn Water Sampler. Samples were placed in pre-cleaned polythene containers and transferred to the laboratory. Samples were then stored at 4^0C until analyzed.

Water quality parameters including temperature, pH, dissolved oxygen (DO), and biochemical oxygen demand (BOD) were measured; and acidity, alkalinity, free carbon dioxide (CO_2), hardness, chloride, calcium and magnesium content were analyzed for each sample. The pH was measured using a digital pH meter (SYSTRONICS 335) equipped with a combination electrode (accuracy $< \pm$ 0.05 pH at 25^0C). Acidity, alkalinity, free carbon dioxide (CO_2), hardness, DO, BOD, chloride, calcium and magnesium were measured by titration methods as described by APHA et al. (1998).

Results and Discussion

The contamination of water bodies by various mining activities is a major environmental problem in Jaintia Hills of Meghalaya. The physicochemical and biological properties of water in various surface water samples were analyzed, and I found that there are spatial and temporal changes in water quality due to mining activities. Multivariate analysis shows that the physicochemical properties of water changes significantly between site and seasons at $P<0.05$, however it did not vary significantly between years and seasons. The changes observed are discussed below.

Multivariate Analysis					
Effect	Wilks Lambda	Ho Df	Error Df	F	Probability
Site	0.040	22	124	22.705	0.000
Years	0.202	11	62	22.272	0.000
Seasons	0.134	33	183	5.442	0.000
Site*Years	0.064	22	124	16.689	0.000
Site*Seasons	0.016	66	337	5.910	0.000
Years*Seasons	0.556	33	183	1.225	0.202
Site*Years*Seasons	0.296	66	337	1.305	0.069

Temperature

Temperature is the basic physical parameter, which alters the characteristics of water quality. During the present study, the maximum temperature (23^{0}C) was observed in the limestone mining area and minimum (18^{0}C) was observed in the coal mining area (Figure 3.1). However there is no considerable variation in the temperature in between the different study sites and seasons (Table 3.1). This is may be due to the edaphoclimatic condition of the study area.

Figure 3.1. Water temperature in the unmined and mining sites of Jaintia Hills

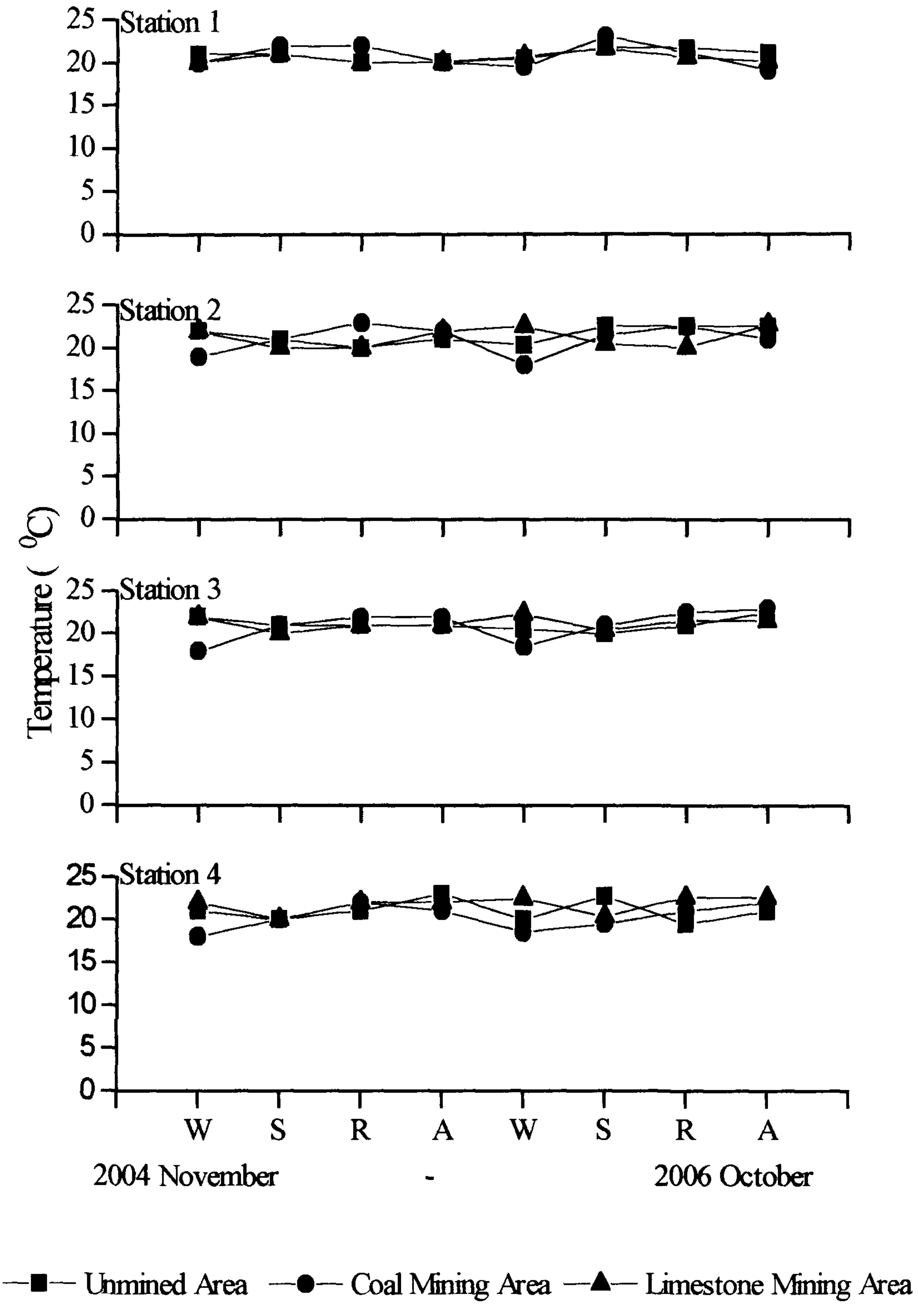


Table 3.1. Results of ANOVA of changes in water temperature in different study sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Temperature	Model	71.550	23	3.111	3.268	0.000
	Error	68.535	72	0.952		
	Total	140.084	95			

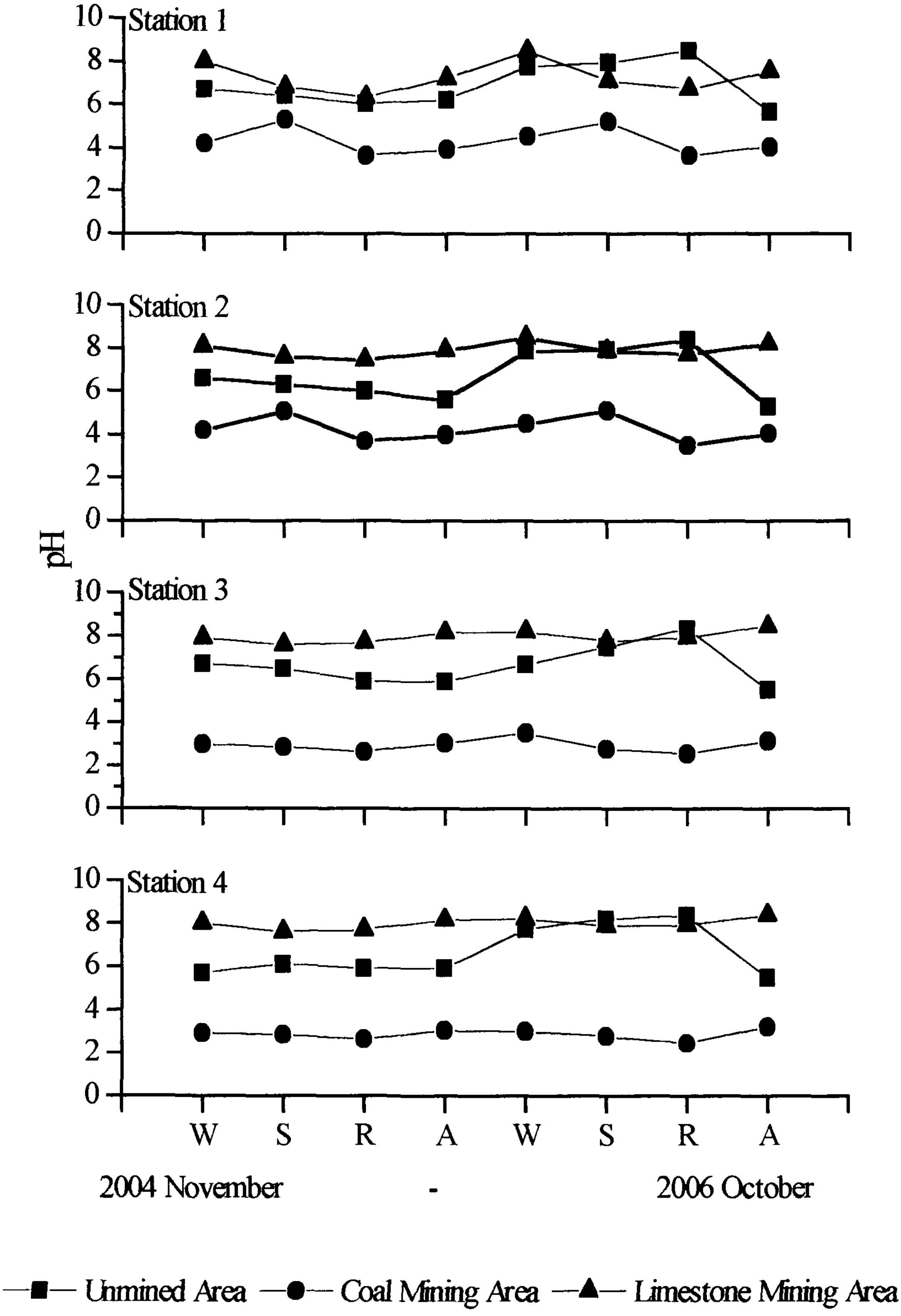
Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Temperature	Site	2.872	2	1.436	1.508	0.228
	Years	0.908	1	0.908	0.953	0.332
	Seasons	13.678	3	4.559	4.790	0.004
	Site*Years	1.393	2	0.696	0.732	0.485
	Site*Seasons	46.447	6	7.741	8.133	0.000
	Years*Seasons	2.168	3	0.723	0.759	0.521
	Site*Years*Seasons	4.085	6	0.681	0.715	0.638

Water pH

The pH of the natural water is controlled by the carbon dioxide/bicarbonate equilibrium, and usually ranges from 4.0 to 9.0. The majority of surface water bodies are slightly basic pH in nature, due to the presence of bicarbonates and carbonates ions. During the present study, it was observed that the pH in the upstream region of the coal mining areas was slightly acidic and became highly acidic in down stream (2.45), however the reverse trend was noticed in limestone mining and unmined area where the pH ranges between 5.3 to 8.5 (Figure 3.2). The result of ANOVA revealed a significant decrease ($P<0.05$) in water pH due to mining from the sites of collection (Table 3.2). The decrease and increase in pH value in coal mining site is due to the discharge of AMD to the river water, and the basic nature of pH water in limestone mining are is due to the high calcium content in the mining waste. The present study is in conformity with the findings of

Figure 3.2. Water pH in the unmined and mining sites of Jaintia Hills



earlier workers Maree et al. (2004) and Adams et al. (2007). Alderton et al. (2005) discussed that the low pH water associated with mining has led to the dissolution of minerals and the mobilization of metals from the mine ores and the host rocks. Laloo et al. (2005) has discussed that the alkaline pH in limestone mining site is due to the dissolution of calcium ions from limestone rocks.

Table 3.2. Results of ANOVA of changes in water pH in different study sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Water pH	Model	972.144	23	42.267	1.568	0.077
	Error	1940.525	72	26.952		
	Total	2912.669	95			

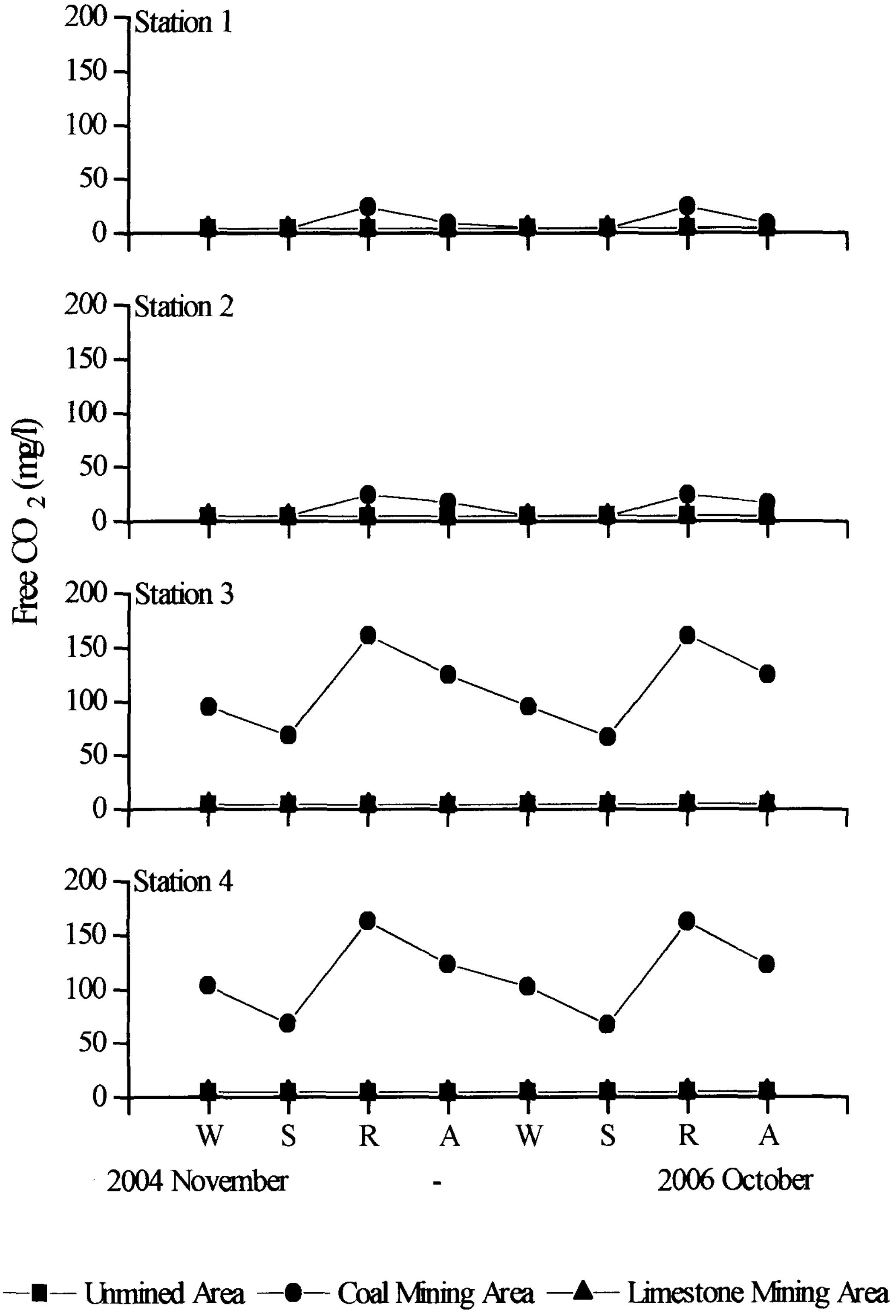
Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Water pH	Site	364.128	2	182.064	6.755	0.002
	Years	23.473	1	23.473	0.871	0.354
	Seasons	49.484	3	16.495	0.612	0.609
	Site*Years	64.521	2	32.261	1.197	0.308
	Site*Seasons	69.600	6	11.600	0.430	0.856
	Years*Seasons	132.939	3	44.313	1.644	0.187
	Site*Years*Seasons	267.998	6	44.666	1.657	0.144

Free CO_2

Free carbon dioxide content of water is regarded as an important index of the deterioration of water quality and is a valuable measure of CO_2 concentration in various aquatic ecosystems. The free CO_2 content at different study sites ranged between 4.05 to 163 mg/l during the study period (Figure 3.3). Marked variation in free CO_2 content values was observed from one station to another in coal mining area, where it increases from upstream to down stream. However, there is not much variation in free CO_2 content

Figure 3.3. Free CO_2 content in the unmined and mining sites of Jaintia Hills



in limestone and unmined site and both the sites are found to have low free CO_2. ANOVA revealed that free CO_2 varied significantly between sites; however it did not vary significantly between seasons and years (Table 3.3). The findings of the present study are similar to the findings of Murugan (2003).

Table 3.3. Results of ANOVA of changes in free CO_2 content in different study sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Free CO_2	Model	99457.339	23	4324.232	2.804	0.000
	Error	111026.027	72	1542.028		
	Total	210483.366	95			

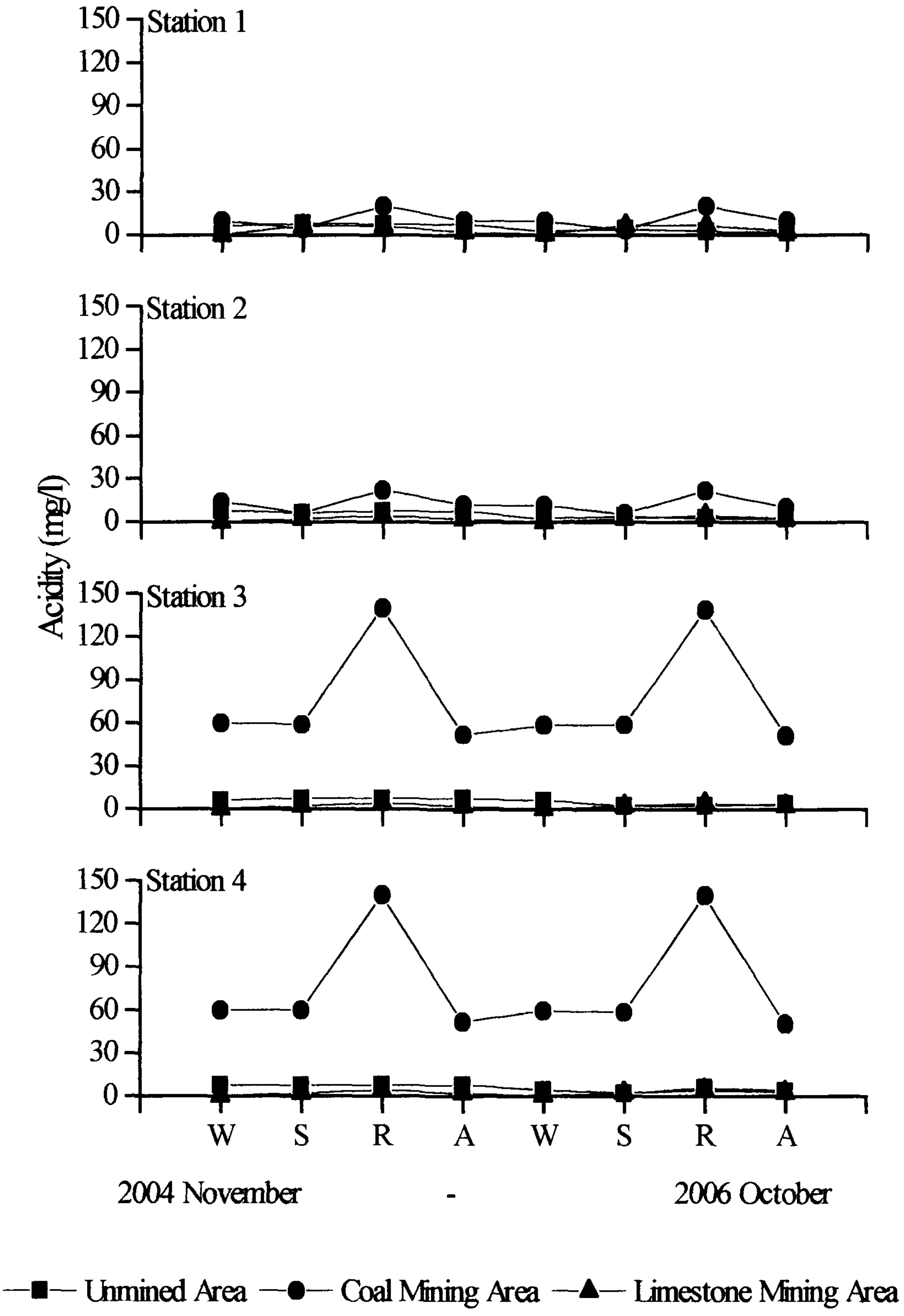
Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Free CO_2	Site	57308.738	2	28654.369	18.582	0.000
	Years	2409.008	1	2409.008	1.562	0.215
	Seasons	12171.440	3	4057.147	2.631	0.057
	Site*Years	4851.605	2	2425.803	1.573	0.214
	Site*Seasons	12394.359	6	2065.726	1.340	0.251
	Years*Seasons	3416.537	3	1138.846	0.739	0.532
	Site*Years*Seasons	6905.652	6	1150.942	0.746	0.614

Acidity

Acidity affects chemical and biological process taking place in water by dissociation of organic and organic molecules. Form the present study, it is observed that high acidity (140 mg/l) in the downstream region of the coal mining area are due to low pH, and low acidity content in limestone was noted (which ranges from 0 to 6.4), and acidity ranged from 2.2 to 8 mg/l in unmined area (Figure 3.4). Test of univariate effects shows that acidity varies significantly ($P<0.05$) between sites and seasons (Table 3.4). The presence of low acidity in limestone mining area could be due to the basic nature of water. High

Figure 3.4. Acidity in the unmined and mining sites of Jaintia Hills



acidity content can be attributed to the formation of sulphuric acid as a product of reactions involving the oxidation of pyrite with the production of acid mine drainage. These high values of acidity agree with findings of Bell and Bullock (1996) and Bullock and Bell (1997).

Table 3.4. Results of ANOVA of changes in acidity of water in unmined and mining sites of Jaintia Hills

Overall tests of univariate models						
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Acidity	Model	62180.224	23	2703.488	3.272	0.000
	Error	59496.034	72	826.334		
	Total	121676.257	95			

Tests of univariate effects						
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Acidity	Site	28976.074	2	14488.037	17.533	0.000
	Years	1244.016	1	1244.016	1.505	0.224
	Seasons	7577.663	3	2525.888	3.057	0.034
	Site*Years	2680.633	2	1340.317	1.622	0.205
	Site*Seasons	14021.948	6	2336.991	2.828	0.016
	Years*Seasons	2549.168	3	849.723	1.028	0.385
	Site*Years*Seasons	5130.722	6	855.120	1.035	0.410

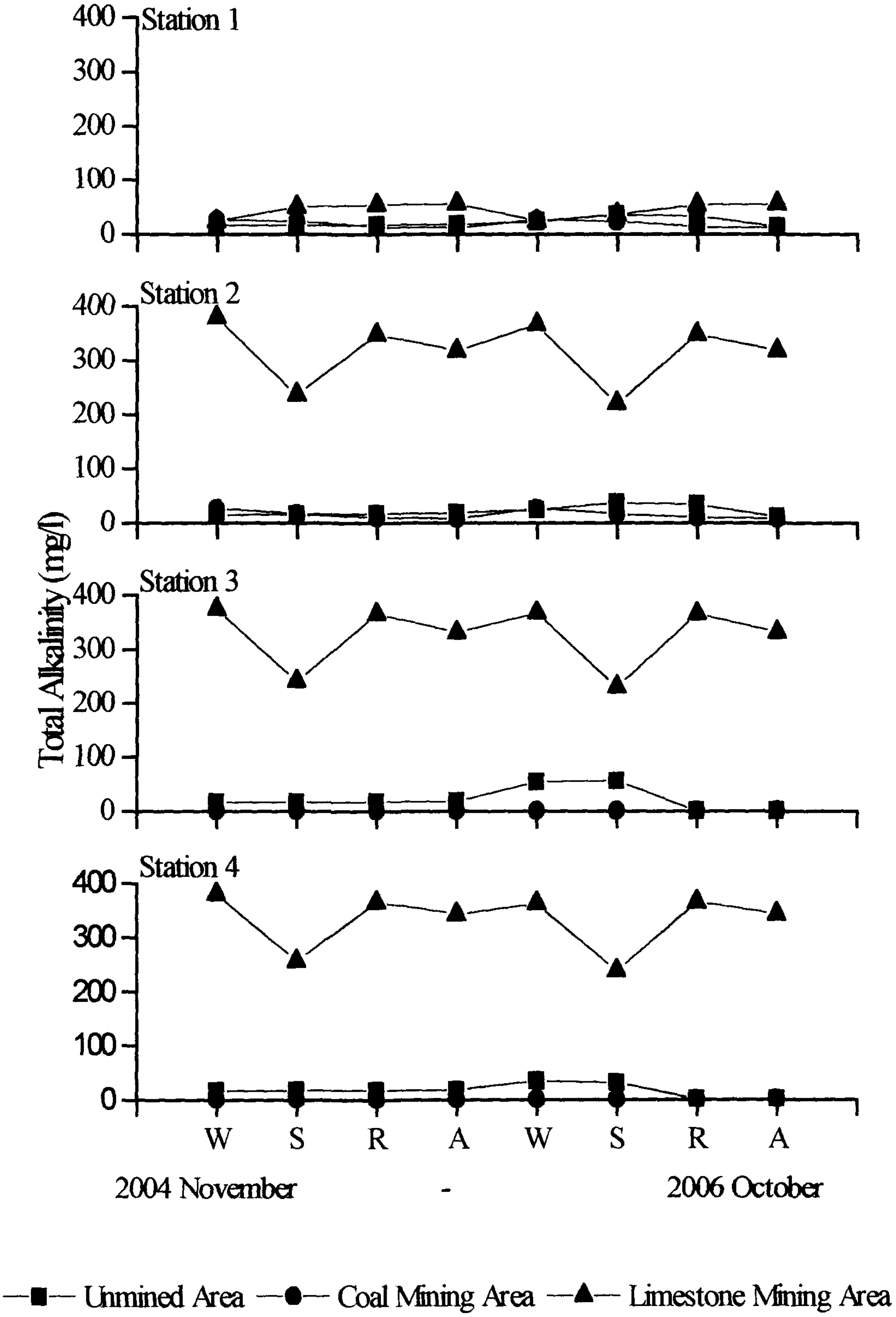
Total Alkalinity

Total alkalinity is regarded as an important index of biological productivity in an aquatic ecosystem. It has been characterized by the presence of hydroxyl (OH^-) ions capable of combining with hydrogen (H^+) ions. A number of bases such as carbonates, bicarbonates, hydroxides, phosphates, nitrates, silicates and borates contribute to the alkalinity. In surface and ground waters, carbonates, bicarbonates and hydroxides are regarded as the predominant bases. During the present study, alkalinity values showed high variation (0 to 380 mg/l) among the various sampling sites. Alkalinity value of the water is low in coal mining and unmined areas, and became significantly higher in limestone mining area, which ranged between 24 to 380 mg/l. In coal mining site, alkalinity was in the range of 1.2 to 26 mg/l, which was still much lower than the alkalinity obtained at the unmined site in the range of 0.6 to 56 mg/l (Figure 3.5). Significant variation in alkalinity was observed among the three study sites at $P<0.05$ level (Table 3.5). The low alkalinity value of the coal mining sites could be attributed to the bicarbonate ions in water. Such conditions are a pointer of low productive level of the water bodies. The alkaline affinity of the limestone mine water is attributed to the occurrence of carbonates and sandstone rocks with calcite cementing materials (Sahabpour et al. 2005).

Table 3.5. Results of ANOVA of changes in alkalinity of water in unmined and mining sites of Jaintia Hills

		Overall tests of univariate models				
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Acidity	Model	62180.224	23	2703.488	3.272	0.000
	Error	59496.034	72	826.334		
	Total	121676.257	95			
		Tests of univariate effects				
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Alkalinity	Site	999336.176	2	499668.088	50.220	0.000
	Years	55190.450	1	55190.450	5.547	0.021
	Seasons	27035.798	3	9011.933	0.906	0.443
	Site*Years	125079.676	2	62539.838	6.286	0.003
	Site*Seasons	101716.571	6	16952.762	1.704	0.132
	Years*Seasons	24497.698	3	8165.899	0.821	0.487
	Site*Years*Seasons	57457.671	6	9576.278	0.962	0.457

Figure 3.5. Total alkalinity in the unmined and mining sites of Jaintia Hills



Total Hardness

The total hardness of water is defined as the sum of the calcium and magnesium concentration. It is not a specific constituent but is a variable and complex mixture of cations and anions caused by dissolved polyvalent metallic ions. The total hardness of water showing wide range of variations, ranged between 0 to 114 mg/l having lower values in the upstream of the coal mining areas (18.5 mg/l) and much lower values in the unmined site (0 to 1.09 mg/l), and further down in the downstream of the coal mining areas, the total hardness recorded was 46 mg/l. In limestone mining areas, higher value (114 mg/l) of total hardness has been recorded (Figure 3.6). The total hardness of water significantly increased ($P<0.05$) with mining activities and also varied significantly ($P<0.05$) between years studied (Table 3.6). The observation of the present investigation showed much wider range of total hardness of water in comparison to the result of the study conducted by Sarma (2002) in coal mining areas of the Nokrek biosphere reserve of Meghalaya.

Table 3.6. Results of ANOVA of changes in total hardness content of water in unmined and mining sites of Jaintia Hills

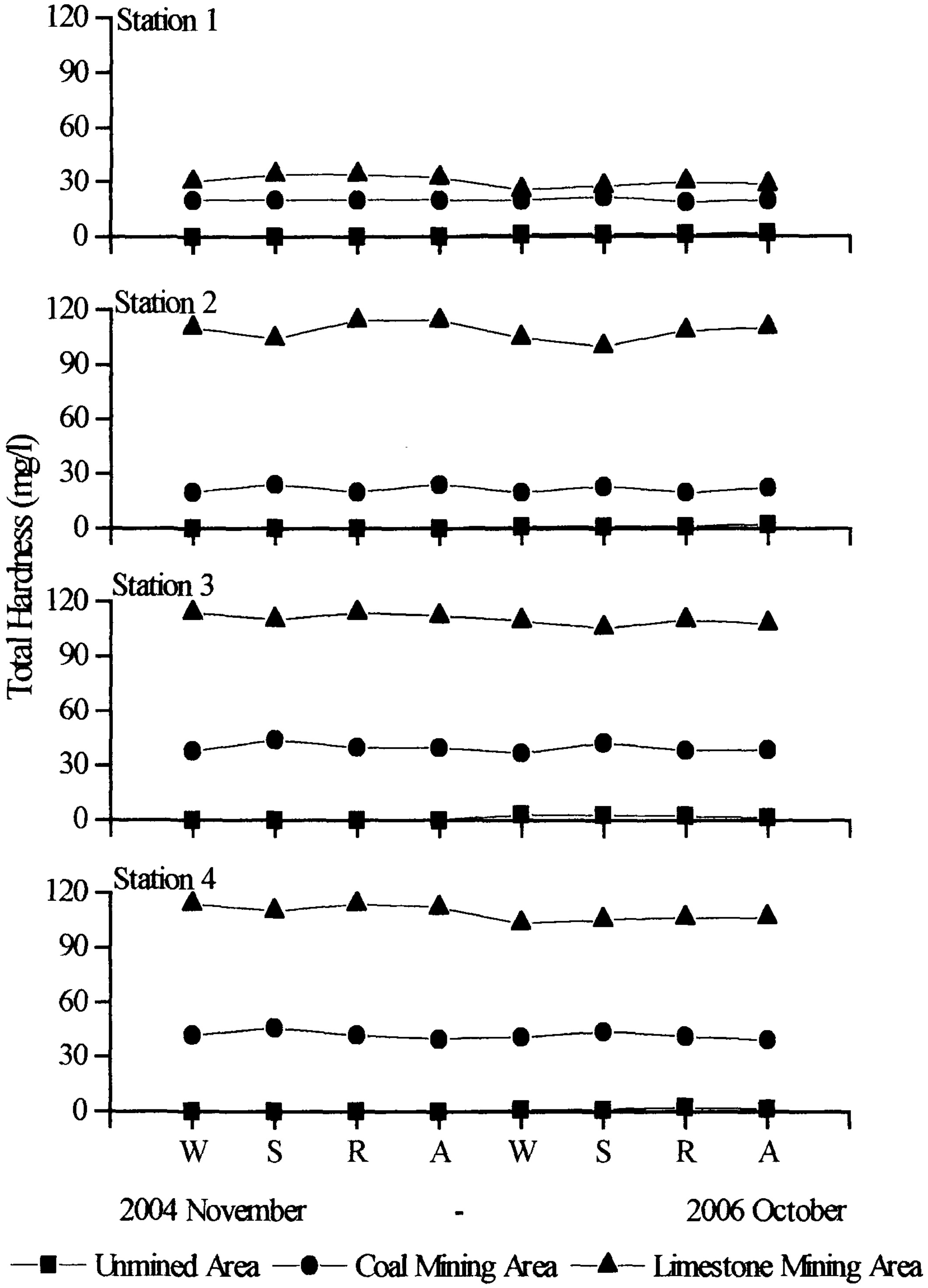
Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Total hardness	Model	117039.565	23	5088.677	6.672	0.000
	Error	54913.995	72	762.694		
	Total	171953.561	95			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Total hardness	Site	68093.395	2	34046.698	44.640	0.000
	Years	10927.787	1	10927.787	14.328	0.000
	Seasons	1400.383	3	466.794	0.612	0.609
	Site*Years	28678.873	2	14339.437	18.801	0.000
	Site*Seasons	3338.104	6	556.351	0.729	0.627
	Years*Seasons	1467.527	3	489.176	0.641	0.591
	Site*Years*Seasons	3133.496	6	522.249	0.685	0.662

Figure 3.6. Total hardness content in the unmined and mining sites of Jaintia Hills



Calcium and Magnesium

Calcium and magnesium are the most abundant cations found in surface waters and hence, they are important contributors to the total hardness of the medium. In the present study, calcium content of the water varied between 0.6 to 65.7 mg/l in different water samples collected from three different study sites of Jaintia Hills. Calcium content in the water in the unmined and coal mining areas are in the range of 0.6 to 3.6 mg/l, which became significantly higher in the limestone mining area and ranged between 3 to 65.7 mg/l (Figure 3.7). The calcium content showed significant variations ($P<0.05$) among different sites studied and showed there is a significant variation among seasons (Table 3.7). It was generally higher in rainy season. The present study is in conformity with the works of Maree et al. (2004). The high calcium content in the limestone mining area is due to the presence of carbonate and calcite cementing materials (Sahabpour et al. 2005).

Table 3.7. Results of ANOVA of changes in Calcium content of water in unmined and mining sites of Jaintia Hills

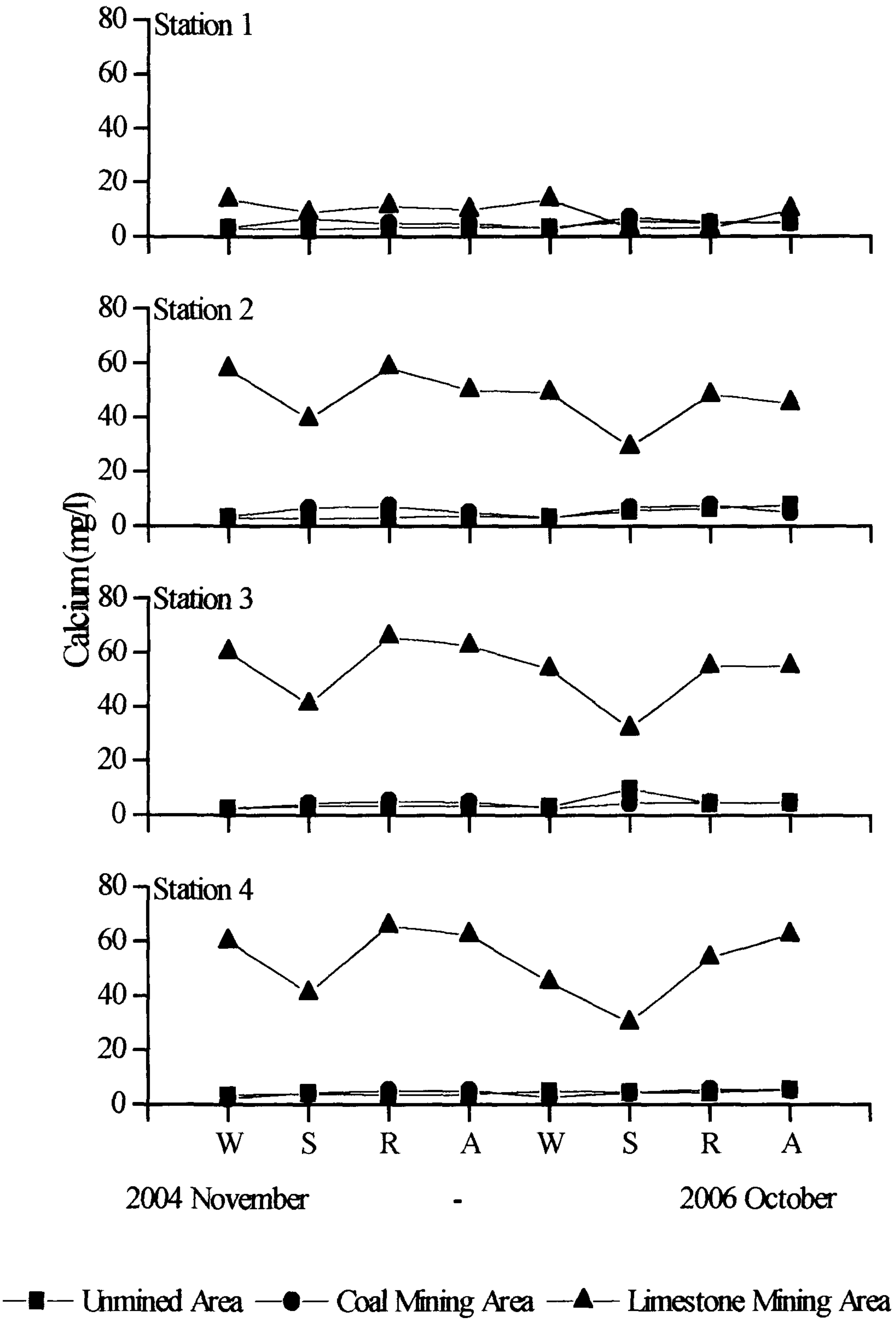
Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Calcium	Model	31005.943	23	1348.084	5.788	0.000
	Error	16769.717	72	232.913		
	Total	47775.661	95			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Calcium	Site	21750.421	2	10875.210	46.692	0.000
	Years	695.527	1	695.527	2.986	0.088
	Seasons	347.549	3	115.850	0.497	0.685
	Site*Years	4134.102	2	2067.051	8.875	0.000
	Site*Seasons	2651.518	6	441.920	1.897	0.093
	Years*Seasons	306.209	3	102.070	0.438	0.726
	Site*Years*Seasons	1120.617	6	186.770	0.802	0.572

Figure 3.7. Calcium content in the unmined and mining sites of Jaintia Hills



Magnesium content ranged between 2.5 to 11.74 mg/l (Figure 3.8). Magnesium content in the water in the unmined areas is in the range of 2.5 to 4.5 mg/l, which significantly increased to 3.11 to 10.7 mg/l in coal mining and 6.65 to 11.74 in the limestone mining areas. The magnesium content in downstream of the coal and limestone mining areas was found to be high (Figure 3.8). Univariate effects revealed that the Magnesium content significantly varied between sites and years (Table 3.8). This is in agreement with the findings of Sharma (2000) in Lodna area of Jharia coalfield in Bihar, and Sarma (2002) in the coal mining areas of Garo Hills, Meghalaya.

Table 3.8. Results of ANOVA of changes in Magnesium content of water in unmined and mining sites of Jaintia Hills

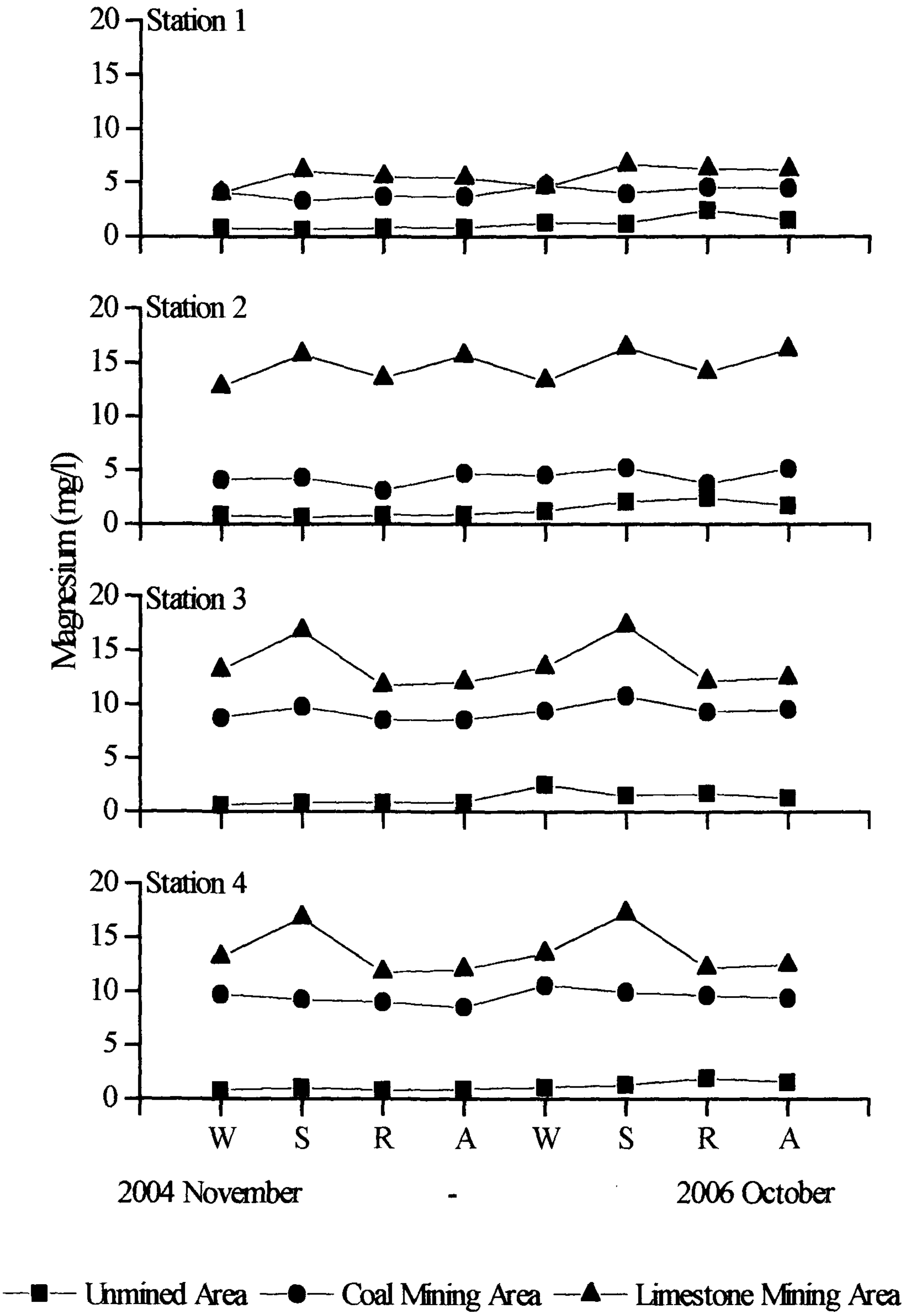
Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Magnesium	Model	2056.233	23	89.401	7.639	0.000
	Error	842.683	72	11.704		
	Total	2898.916	95			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Magnesium	Site	805.719	2	402.860	34.421	0.000
	Years	440.627	1	440.627	37.648	0.000
	Seasons	43.529	3	14.510	1.240	0.302
	Site*Years	649.598	2	324.799	27.751	0.000
	Site*Seasons	67.111	6	11.185	0.956	0.461
	Years*Seasons	16.130	3	5.377	0.459	0.712
	Site*Years*Seasons	33.520	6	5.587	0.477	0.823

Figure 3.8. Magnesium content in the unmined and mining sites of Jaintia Hills



Chloride

Chloride is regarded as a valuable indicator of water quality. It is also a conservative ion but plays a metabolically active role in the photosynthesis of water and phosphorylation in autotrophs. Chloride anion is naturally present in surface waters and it can be attributed to dissolution of salt deposits and effluents from industrial waste and cause the contamination of aquatic bodies. A high concentration of chloride is an indicator of pollution.

In the present study, the general concentration of chloride ions ranges between 1.35 to 32.9 mg/l. Chloride content in the water from unmined area was found to be low and is in the range of 1.8 to 7.1 mg/l. The chloride concentration, well within the specified limits, is usually found in fresh waters. The chloride content became significantly higher ($P<0.05$) in the limestone mining areas and ranged between 1.35 to 18.1 mg/l. Furthermore, the chloride content in the coal mining site ranges from 7.1 to 32.9 mg/l, which was far higher than the chloride content obtained in the other sites (Figure 3.9). ANOVA revealed that the chloride content of water significantly ($P<0.050$) varied among sites and years and sites and seasons. The present study is in agreement with the findings of Brake et al. (2001) who conducted the study on the impact of mine drainage on the geochemistry of West Sugar Creek pre- and post- reclamation at the Green Valley coalmine in Indiana, United States of America. Increase in Cl^- concentrations reflects anthropogenic effects of surface water in mining areas.

Figure 3.9. Chloride content in the unmined and mining sites of Jaintia Hills

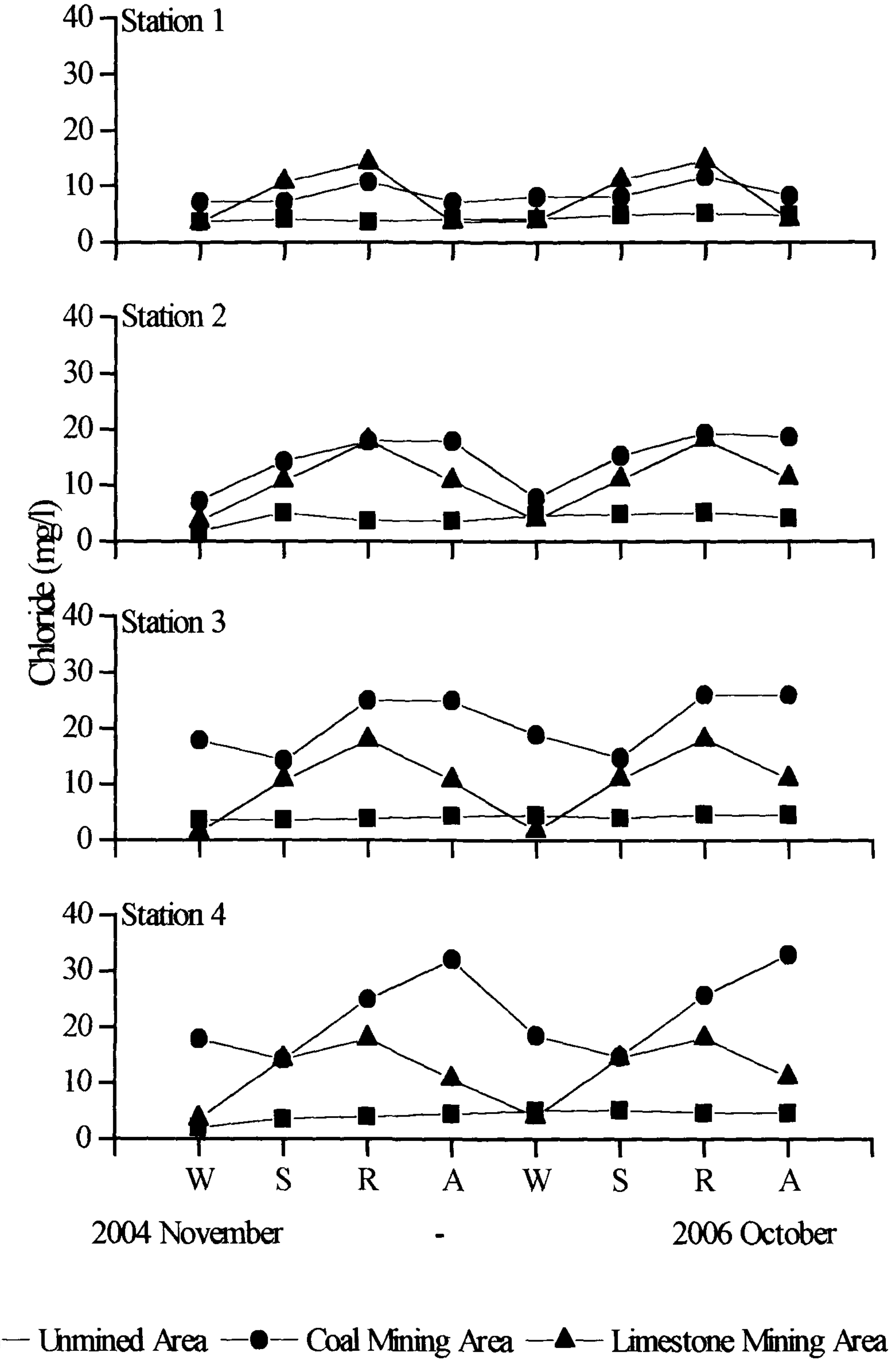


Table 3.9. Results of ANOVA of changes in Chloride content of water in unmined and mining sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Chloride	Model	3706.255	23	161.142	6.625	0.000
	Error	1751.216	72	24.322		
	Total	5457.471	95			

Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
Chloride	Site	1053.913	2	526.957	21.665	0.000
	Years	467.063	1	467.063	19.203	0.000
	Seasons	748.310	3	249.437	10.255	0.000
	Site*Years	699.214	2	349.607	14.374	0.000
	Site*Seasons	642.204	6	107.034	4.401	0.001
	Years*Seasons	32.779	3	10.926	0.449	0.719
	Site*Years*Seasons	62.772	6	10.462	0.430	0.857

Dissolved Oxygen (DO)

The concentration of DO in freshwater and wastewater depends on the physical, chemical and biological process in an aquatic ecosystem. Since DO is essential for the biota of an ecosystem and for the aerobic degradation of organic pollution, the measurement of DO is important in wastewater treatment. Non-polluted surface waters are generally saturated with DO. However in polluted waters, due to the presence of oxygen demanding pollutants like organic waste, rapid depletion of DO take place. Oxydizable inorganic substances such as hydrogen sulphide, ammonia, nitrites and ferrous iron also bring about a wide decrease in DO content.

The dissolved oxygen content in the study area showed a wide range of variation varying from 1.0 to 8.7 mg/l. DO content in the water from unmined site was in the range of 7.3 to 8.7 mg/l, which reduced to 5.0 to 6.8 mg/l in mining areas. In the downstream of the coal mining area during rainy season, very low DO was recorded (Figure 3.10). ANOVA shows the significant variation in mining and unmined sites (Table 3.10). However, it did not show much seasonal variation among the different sites except towards downstream of the coal mining area. Rapid discharge of AMD may explain the relative high concentration of acidity, low pH and low DO content in the surface river water. This is in agreement with the work of Lee et al. (2005) in their study of water contaminated with toxic metals in abandoned mine sites of Korea.

Table 3.10. Results of ANOVA of changes in DO content of water in unmined and mining sites of Jaintia Hills

Overall tests of univariate models

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
DO	Model	76.097	23	3.309	17.680	0.000
	Error	13.473	72	0.187		
	Total	89.570	95			

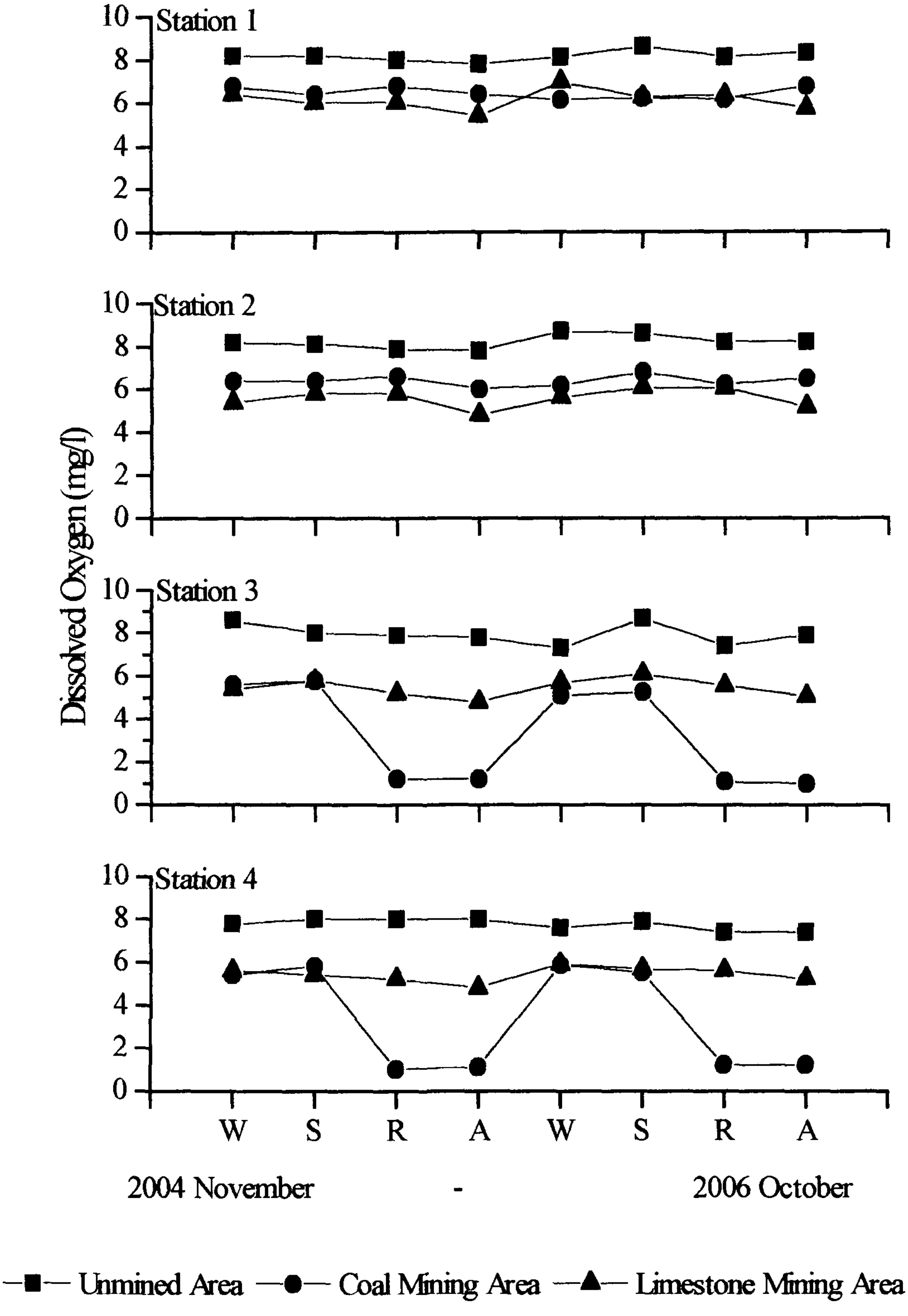
Tests of univariate effects

Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
DO	Site	30.779	2	15.389	82.238	0.000
	Years	3.245	1	3.245	17.341	0.000
	Seasons	1.347	3	0.449	2.400	0.075
	Site*Years	31.124	2	15.562	83.161	0.000
	Site*Seasons	6.311	6	1.052	5.621	0.000
	Years*Seasons	1.125	3	0.375	2.005	0.121
	Site*Years*Seasons	2.166	6	0.361	1.929	0.088

Biological Oxygen Demand (BOD)

The amount of oxygen consumed by the microorganisms to break down waste is known as biochemical oxygen demand. The BOD is the most commonly used parameter in the analysis of oxygen resources in water. The BOD concentration in the study area ranged from 1.00 to 41.6 mg/l. In the unmined areas, BOD ranges from 1 to 3.41 mg/l, which is

Figure 3.10. DO content in the unmined and mining sites of Jaintia Hills



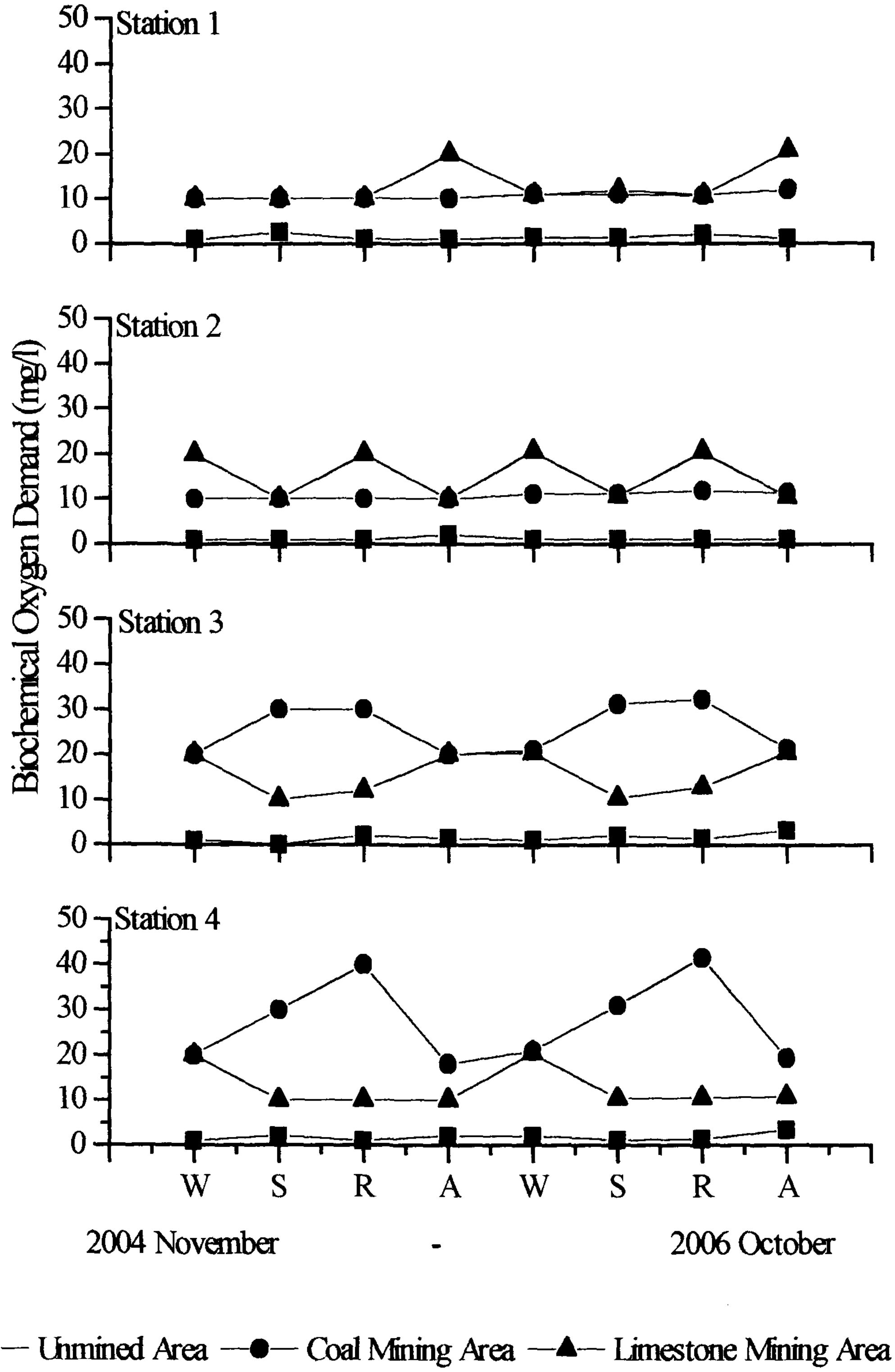
significantly low. However, coal mining areas and limestone-mining areas contain high BOD value, which ranges from 10 to 41.6 mg/l and 20 to 20.51 mg/l respectively (Figure 3.11). Test of univariate effects shows BOD varied significantly ($P<0.05$) between sites and years studied (Table 3.11), but not much variation was observed between sites and seasons. The high BOD content in mining site is due to the discharge of AMD. The measurement of BOD provides a direct measure of the potential impact of oxygen consumption on the oxygen content of an aquatic ecosystem (Baumgartner 1996).

Table 3.11. Results of ANOVA of changes in BOD content of water in unmined and mining sites of Jaintia Hills

		Overall tests of univariate models				
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
BOD	Model	4642.493	23	201.848	3.469	0.000
	Error	4189.128	72	58.182		
	Total	8831.621	95			

		Tests of univariate effects				
Y Variable	Source	Type III SS	Df	Mean Sq.	F	Probability
BOD	Site	1217.127	2	608.563	10.460	0.000
	Years	964.441	1	964.441	16.576	0.000
	Seasons	170.432	3	56.811	0.976	0.409
	Site*Years	1410.979	2	705.490	12.125	0.000
	Site*Seasons	670.295	6	111.716	1.920	0.089
	Years*Seasons	76.140	3	25.380	0.436	0.728
	Site*Years*Seasons	133.080	6	22.180	0.381	0.889

Figure 3.11. BOD content in the unmined and mining sites of Jaintia Hills



Chapter 7

General Discussion

Exploration, extraction and utilization of minerals are important for the economic growth and development of a country and mining is considered as one of the most essential activity next to agriculture. However, continued exploitation of natural resources frequently involves a high degree of environmental disturbance, which can extend well beyond the extent of mineralized areas. Large sale denudation of forest cover, conversion of green belts into barren lands, transformation of agricultural lands into wastelands, dumping of waste materials and pollution of air, water and soil are some of the common consequences of mining (Singh 2005; Jeeva et al. 2007a).

Terrestrial and aquatic ecosystems in mining areas become adversely contaminated leading to loss of biodiversity and depletion of other natural resources. Water resources, in particular, are under serious threat both in terms of their quality and quantity. All such environmental perturbations exert tremendous pressure on human health and socio-economic fabric of the society. These in turn, have multifaceted repercussion at local, regional and global level (Singh 2007; Jeeva et al. 2007b,c).

Jaintia Hills of Meghalaya has rich biodiversity as well as large reserve of natural resources. During the last few decades, there has been phenomenal increase in coal mining and limestone extraction that have caused massive damage to landscapes and biological communities. The present study reported that, the total number of aquatic plants present in the coal mining sites is significantly lesser than in unmined sites. This may be because of the alteration of pH due to mining activities. However, no aquatic plants were recorded in the limestone mining area. This could be attributed to the presence of high calcium content of water in the limestone mining area.

The natural plant communities are disturbed by mining activity and the habitats of the plant communities are disturbed by coal mining and limestone extraction, which become impoverished presenting a very rigorous condition for plant growth. From the present observations, it was found that the number of tree species got reduced due to mining. The unfavorable habitat conditions prevailing in the coal mining areas might have reduced the regeneration of many tree species, thereby reducing the number of tree species in the mined areas. Similar observations were made in studies conducted in the coal mining areas of Nokrek Biosphere Reserve, Meghalaya (Sarma 2004; 2005). The number of shrub and herbaceous species colonizing the mining areas was found to be higher than in the unmined sites. This could be due to the better ability of understorey species to adapt to the disturbed habitats.

It has been argued that ecosystems with high species diversity are more stable and resilient to environmental disturbances than those having low species diversity (Frank and McNaughton 1991; Tilman and Downing 1994). The total density of the tree species was high in unmined sites than the mining areas. However, in case of shrubs and herbs the reverse trend was observed in terms of density. Similar result was obtained from the study conducted by Sarma et al. (2005) in mining areas of the Garo Hills of Meghalaya, and they also found high basal cover in the unmined site than the mining site.

Importance value index of tree species was low in the mining sites than the unmined sites. However, some tree species growing in mining areas are found to have high IVI. This could be attributed to the existence of large diameter trees, which incurs minimal damage during mining operation. Distribution pattern shows most of the tree species in mining and unmined sites are contagious. Due to mining, the contagiousness increased. This is in agreement with the findings of Rao et al. (1990) and Mishra et al. (2004) who observed that due to disturbance, contagiousness increased.

The density-circumference breast height (CBH) distribution of tree species indicated that the density of trees irrespective of their girth class was lower in the mined sites than the unmined sites. The basal areas of the tree species in the unmined site were significantly higher than in the coal and limestone mining areas. Similar trend were also observed by Newbery et al. (1992) in diptercarp forests of the Danum valley, Malaysia; Parthasarathi and Karthikeyan (1997) in Courtallum reserve forest of Southern Western Ghats, and Sarma et al. (2004) in coal mining sites of the Nokrek Biosphere Reserve of Meghalaya.

The regeneration pattern of tree species showed that better seedling recruitment in unmined site than in mining site. Similar trend was observed in the percentage conversion of seedlings into saplings. Rodrigues et al. (2004) conducted the regeneration study in tropical rainforest degraded by mining and suggested that the conservation of the forest area degraded by mining was essential for the natural regeneration of tree species, acting as a seed source and refuge for dispersers. They also discussed that the pioneer species alters the ecological conditions and thus facilitates the regeneration of late secondary species.

The adverse effect of mining activity is soil and water contamination. Physicochemical properties of soil were badly affected due to coal mining. Due to coal mining soil pH was acidic in nature, the reverse trend was observed in limestone mining area, i.e. the pH was alkaline nature. However, the soil present in the unmined areas was less acidic in nature. It could be due the edaphoclimatic condition, because the forests of Meghalaya receive high rainfall that leads the high litter accumulation and leaching of the organic matter from the plant residues on to the forest floor. The acidic nature of soil in coal mining area is due to the sulphur content oozing out from the acid mine drainage.

Soil nutrient levels are the reflection of the organic matter content and the availability of Nitrogen, Phosphorus and Potassium. The low amount of soil nutrients in the mining sites observed in the present study agrees with the findings of Sankar et al. (1993) who conducted the study in coal mining areas of Cherapunjee, the wettest place in the world, and reported low level of organic carbon in the mining areas and attributed it to the delay in vegetation establishment on the mine spoil. Besides, the organic carbon content in both coal and limestone mining area is low because soil particles on the surface layer are generally brought from deeper horizon, which are devoid of any organic matter (Sarma 2002).

The rivers and streams of Jaintia Hills are the major victims of the coal mining. Contamination of acid mine drainage, leaching of heavy metals, organic enrichment and silting are some of the major causes of water pollution. Majority of AMD contaminations cause acidity of the contaminated water bodies. The pH of the water in the downstream of the coal mining site was highly acidic and the reverse trend was observed in the limestone mining site, where it was alkaline in nature. This indicates serious condition of the water bodies of the area that hardly can support any aquatic organisms. The finding of the present study is in agreement with the results of Singh and Swer (2004) in their study of coal mining areas of Jaintia Hills Meghalaya.

The hardness of water, calcium and magnesium concentration increased due to mining. Singh (2007) found similar results in the coal mining areas of Meghalaya. Swer and Singh (2005) discussed that secondary effects such as increased CO_2 tensions, oxygen reduction by the oxidation of metals, increased osmotic pressure form high concentration of minerals, and synergistic effects of metal ions also contribute to toxicity.

Water quality of mining area has degraded to the extent that rivers and streams are loosing their life sustaining role and becoming devoid of aquatic life. The findings of the present study shows that low DO and high BOD in mining areas is due to the organic enrichment of water bodies due to mining activities leading to lower DO and high BOD levels in water and is in conformity with the work of Sarma (2002) and Jeeva et al. (2006) in the mining areas of Meghalaya. This has further made the environment unfit for survival of aquatic life. Consequently, the same rivers and streams that supported human life and activities and rich biodiversity have become endangered. Under prevailing grave conditions of water quality and aquatic biodiversity in rivers and streams of Jaintia Hills, there is an urgent need for initiating activities for ecorestoration of the affected areas. Extensive afforestation and neutralization of acidic seepage, and management of AMD will go a long way in restoration of the lost environmental glory of the area.

Chapter 8

Summary and Conclusion

Mining operations have a number of irreversible impacts on the surrounding environment and ecosystems. The more obvious impacts are deforestation, changes in soil and water regimes and enhanced rates of erosion. Mining operations alter ecosystem structure and function of both aquatic and terrestrial ecosystems. Environmental problems associated with mining have been felt severely because of the region's fragile ecosystems and rich biological and cultural diversity.

Large scale denudation of forest cover, scarcity of water, pollution of air, water and soil and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining. Besides, a vast area have become physically disfigured due to haphazard dumping of overburden, caving in of the ground, and subsidence of land. The impact of mining on vegetation, soil and water quality of Jaintia Hills of Meghalaya was significant.

Form the present study, I found that aquatic plants are present only in the upper stream of the coal mining area and was high in the unmined area, however no aquatic plants were recorded in the limestone mining area.

Tree species shows a drastic reduction in their species composition due to mining activities. The total number of tree species was high in unmined site than in coal and limestone mining sites. However, shrub and herb species was found to be high in mining sites than in unmined site.

Similar trend was also observed in case of density of trees, shrubs and herbs. The diversity indices for tree species in the mining sites were low, which indicates adverse impact of coal mining and extraction of limestone.

Total basal area of the tree species shows a significant variation in between the sites. In the unmined site, the basal area was higher than in the coal and limestone mining sites and suggests that mining adversely affect the basal cover of the tree species.

Regeneration of tree species and seedling and sapling density was high in the unmined areas than in the coal and limestone mining sites. The percentage conversion of seedling to saplings was also found to be fairly high in unmined areas compared to mining areas.

Many native tree species found in the mining sites which could not regenerate due to mining activities and results into local extinction. However, understorey species especially shrubs and herbs colonized the areas following mining. The colonization of these secondary successional species is in agreement with the intermediate disturbance hypothesis that justifies higher species diversity of understorey species due to disturbance.

From the present study, it was also observed that the physicochemical characteristics of soil were adversely affected due to mining. The soil became acidic in coal mining areas and slightly alkaline in limestone mining areas. Soil organic carbon and nitrogen content was drastically reduced due to mining activity. The deterioration of soil physicochemical properties would have detrimental effect on the soil biota. The impact of mining on soil not only affects the soil physicochemical properties but it also affects the growth of plant species and creates a stressful environment.

The most severe environmental impact of mining activity is degradation of water quality. The water in the downstream of the coal mining area was highly acidic, on the contrary in limestone mining area it was found to be alkaline. The hardness of water, calcium and magnesium content also changed due to mining activity. Chloride content increased due to mining. The impact of AMD was more acute during rainy season. These changes make the water polluted unusable even for agricultural purposes.

Low DO and high BOD were recorded especially in the down stream of the mining sites. The results indicate that mining alters the biological and physicochemical properties of water in the aquatic ecosystems of the mining areas.

Based on the findings of the present study, it is revealed that coal mining and limestone extraction has adversely affected the aquatic and terrestrial ecosystems of Jaintia Hills, Meghalaya. The outcome of the vegetation analysis, especially the species having high IVI, regeneration potential, stress tolerance and economically important native species would be helpful in revegetation of the mined areas.

The findings of the physicochemical properties of soil and water will be helpful in the bioamelioration of aquatic and terrestrial ecosystem of Jaintia Hills, Meghalaya affected by mining activities.

From the present study, it is evident that mining activities adversely affect the aquatic and terrestrial ecosystems of Jaintia Hills, Meghalaya. There is an urgent need for reversing the trend and bringing back the area to its original state. Filling of mine pits, channeling of seepage water for checking AMD contamination of water bodies and agricultural fields, afforestation with native and fast growing tree species, undertaking effective soil conservation and water resources management programmes are some of the measures which can mitigate the problem and restore the degraded ecology for conservation of aquatic and terrestrial ecosystems of the Jaintia Hills, Meghalaya.

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